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Offices—Aldine House, Bedford Street, Strand, London, W.C. 2.
Telegrams: Instpetech, Westrand, London.
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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

NOTICES.

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Copyright. Authors of papers and articles are requested to transfer their copyright to the Institution for a period of six months from the date of receipt of the paper. Such transfer should be made in writing when the manuscript is forwarded to the Editor.

Editors are permitted to publish abstracts, providing that acknowledgment is made to The Institution of Petroleum Technologists.

Issue of Journal. The Journal is issued in nine parts per volume, commencing in January of each year, with occasional extra numbers when necessary. The Title Page, Table of Contents and Index to each volume are published in the second issue of the succeeding volume.

Members whose subscription is not in arrear receive the Journal free of cost, and additional copies are charged at the rate of 7s. 6d. per part, unless otherwise stated. A member whose subscription is not paid by March 31st of the year for which it is due is considered to be in arrear.

Changes of Address. Members are requested to notify any change of address to the Secretary.

Papers and Articles. Members are invited to submit papers to be read at the General Meetings of the Institution, and are specially asked to forward articles for consideration for publication in the Journal. Diagrams, illustrations, etc., should be suitable for direct photographic reproduction. Authors are informed that all papers, whether for reading or for publication, will be submitted to a referee nominated by the Publication Committee.

Authors of papers published in the Journal are entitled to receive 25 free reprints of their contribution. Further copies may be obtained on payment, and orders for these should be sent to the Secretary when the manuscript is forwarded to the Editor. The free reprints do not include any discussion which may be published with the paper, but authors may have such discussion included in their reprints on payment of the additional cost.

Galley proofs of the paper to be read at a General Meeting are available at the time of the meeting, but members desirous of receiving such galley proofs in advance should apply to the Secretary.

Binding of Journals. Members desiring to have their Journals bound in cases should send them, together with a remittance of 5s. 6d. per volume, to Messrs. Spenight & Sons, Ltd., 98, Fetter Lane, London, E.C. 4. A charge of 7s. 6d. will be made for binding Vol. 10, 1924. Remittance in all cases must accompany the order.

Abstracts. Abstracts of the more important articles and patent specifications are published with each issue of the Journal, this supplement being paged independently of the transactions. Members desiring to have the Abstracts printed on one side of the

paper only can be supplied with uncorrected galley proofs at a charge of 10s. per annum per copy, payable in advance.

Medals. The Redwood Medal is awarded, at the discretion of the Council, to the person who shall have made the most meritorious contribution to petroleum technology, in the form of a paper or papers published in the Journal of the Institution, during two successive sessions, preference being given to original work and to papers which have been read before the Institution and discussed. The award is not confined to members of the Institution and may be withheld if no contribution is considered to be of sufficient merit.

A medal and a prize of five guineas is awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented the best paper during the session.

Research Fellowship. The sum of £300 is allocated in each calendar year to a Fellowship for Research in technical and scientific problems which have a direct bearing on the Petroleum Industry. Additional grants, to a limit of £50 per annum, may also be made towards expenses.

The Fellowship is tenable for one year at an institution or in works approved by the Council, and may be renewed for a second year at the discretion of the Council.

Applicants, other than members of the Institution, must be of British nationality and must hold an Honours Degree in Science or an approved equivalent.

Applicants for the Fellowship must be in the hands of the Secretary of the Institution not later than June 1st of each year, and the necessary form, together with full particulars, can be obtained from him at Aldine House, Bedford Street, London, W.C. 2.

Benevolent Fund. The Benevolent Fund is intended to aid necessitous persons who are or have been members of the Institution, and their dependent relatives.

The Fund is raised by voluntary annual subscriptions, donations, and bequests, and all contributions should be sent to the Secretary of the Institution at Aldine House, Bedford Street, London, W.C. 2. The Fund is administered by the Council through the Benevolent Fund Committee, and all applications in connection therewith must be made on a special form which can be obtained from the Secretary of the Institution.

Appointments Register. A register of members requiring appointments is kept at the office of the Institution for the convenience of firms requiring the services of petroleum technologists, etc., it being understood that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library may be consulted between the hours of 11 a.m. and 4 p.m. daily. (Saturdays, 11 a.m. to 12 noon.)

Advertisements. Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from Mr. Thomas Tofts, 301-302, Bank Chambers, 329, High Holborn, W.C. 1. (Telephone No. Hol. 4776.)

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Mr. A. F. CASTLE is home from Iraq.

Mr. G. S. FFOULKES-JONES is home from Venezuela.

Mr. W. J. GALLOWAY is home from Persia.

Mr. A. D. JONES has returned to Burma.

Mr. R. H. S. HAYDON has left for Iraq.

Mr. W. S. LAMB has returned from Burma.

Dr. E. PARSONS is returning from British East Africa.

Mr. P. N. D. PORTER is in Rumania.

Mr. J. S. SMITH is home from Ecuador.

Mr. P. VICKERS has left for Philadelphia, Pa., U.S.A.

The Secretary would be glad to hear of the whereabouts of the following members :—C. A. BAUDUIN, A. E. O. COOKE, A. F. H. GEE, W. J. HARRIS, L. B. HOLLOWAY, A. F. C. PARKER, NAND LAL PASI, W. E. SHEPHERD, R. K. VAN SICKLE and F. E. G. WATSON.

OBITUARY.

Major Sir RICHARD WHIELDON BARNETT, M.A.

We deeply regret to announce the death of Major Sir Richard Whieldon Barnett, M.A., which occurred at his home at Park Lodge, Park Village West, London, N.W.,-on October 17th, 1930, after an illness of several months.

Sir Richard Barnett was elected a Member of the Institution of Petroleum Technologists in 1914, a Member of Council in 1915 and a Vice-President in 1929. He was keenly interested in the work of the Institution, and his presence at the Council and Committee meetings will be greatly missed.

He was a notable figure in the Petroleum Industry, and at the time of his death was President of the British Controlled Oilfields, Ltd., Chairman of the Baku Consolidated Oilfields, Ltd., and of the Oilfields Finance Corporation, Ltd., and a Director of the Trinidad Lands Reclamation, Ltd., and of the Trinidad Petroleum Development Corporation, Ltd. He was also a Vice-President of the Oil Industries Club.

Born on December 6th, 1863, he was the eldest son of the late Dr. Richard Barnett, of Ardmore, County Down, Ireland. He was educated privately and then went to Wadham College, Oxford, where he obtained honours in jurisprudence and graduated B.A. in 1887. In 1889 he took his M.A. and B.C.L., and in the same year was called to the Bar at the Middle Temple, subsequently joining the South-Eastern Circuit.

His parliamentary career commenced in 1916, when he was elected as the Member for West St. Pancras. In 1918 he was elected for the South-West St. Pancras division and retained this seat until his retirement in 1929. In 1919 he introduced the Nurses' Registration Bill, and in 1920 carried a resolution favouring increased pensions for superannuated railway servants. He sat on the Chairmen's Panel for Grand Committees, attended all the Inter-Parliamentary Conferences from 1917 to 1928, and in 1928 was appointed Acting President for the Conference at Versailles. He also presided over the Commercial Committee of the House of Commons during 1923-1924.

He was a noted rifle shot and in 1879, at the age of fifteen, won the Championship of Ireland, which country he represented thirty-seven times in matches for the Elcho Challenge Shield, twice making the record score. In the Olympic Games of 1908 he was a member of the United Kingdom team, and from 1921 to 1928 was Captain of the House of Commons team against the Lords. He was also a Member of Council of the National Rifle Association. On his

retirement from Parliament he presented to the House of Commons the Wimbledon Cup, which he won at the N.R.A.'s last meeting there in 1889.

While at Oxford he was a Captain in the Oxford University Volunteers, and later, from 1889 to 1897, was Captain and Musketry Instructor in the 22nd Middlesex Rifle Volunteers. At the outbreak of the Great War he was appointed Musketry Officer of the 41st. Infantry Brigade and graded as Brigade Major, and two months later, in November, 1914, he was transferred to a similar appointment in the Ulster Division, and in 1915 to the 40th Division. He designed the Barnett Optical Sight for the S.M.L.E. rifle, and was promoted Brevet-Major in 1919. In 1925 he was Knighted.

As a Freemason he was President of the Board of Grand Stewards of England, 1909-1910, and Past Deputy Grand Sword Bearer, 1922.

His recreations also included chess and golf, and he was the champion chess player of Ireland from 1886 to 1889. He greatly assisted in the revival of the House of Commons Chess Circle, of which he was President from 1923 to 1929, and was Chairman of the Executive Committee of the British Chess Federation.

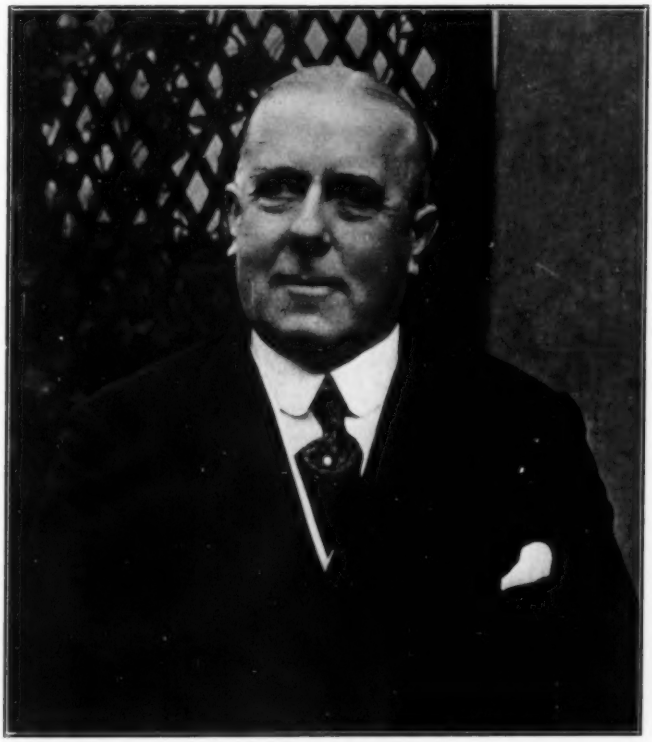
THIRD (TRIENNIAL) EMPIRE MINING AND METALLURGICAL CONGRESS.

THE Proceedings of the Third (Triennial) Mining and Metallurgical Congress, held in South Africa from March 24th to May 9th, 1930, are shortly to be published in four volumes. Part I. will contain the Report of Proceedings, Inaugural and other Addresses, Papers and Discussions, South Africa, General; Part II., Papers and Discussions, Witwatersrand Mining; Part III., Papers and Discussions, South African Mining, ex Witwatersrand; Part IV., Papers and Discussions, General.

The price of the complete set of four volumes, bound in full cloth and lettered in gold, is £2 2s., and orders should be sent to the General Secretary of the Congress, Kelvin House, 100, Fox Street, Johannesburg, South Africa.

DINNER CLUB.

The attention of members is drawn to the Dinner Club of the Institution. This Club holds informal dinners after each General Meeting of the Institution and members may invite guests. Those desiring to receive notice of these dinners, are requested to inform the Secretary of the Institution.



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MAJOR SIR RICHARD WHIELDON BARNETT, M.A.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

Under the Order in Council dated February 6th, 1928, the Lord President of the Council has appointed Mr. E. J. Butler, C.I.E., D.Sc., M.B., F.R.S.; Mr. Kenneth Lee, LL.D.; and Mr. N. V. Sidgwick, O.B.E., Sc.D., F.R.S., to be Members of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research.

The following Members of the Advisory Council have retired on completion of their terms of office: Prof. V. H. Blackman, Sc.D., F.R.S. (Chairman since April, 1930); Prof. F. G. Donnan, C.B.E., D.Sc., LL.D., F.R.S.; and Prof. F. A. Lindemann, Ph.D., F.R.S.

The appointment of Prof. Sir Ernest Rutherford, O.M., President of the Royal Society, to be Chairman of the Advisory Council as from October 1st, 1930, was announced in May last.

NOMINATIONS FOR MEMBERSHIP OF THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The following have been nominated for membership of the Institution of Petroleum Technologists and their Application Forms may be seen at the Offices of the Institution:—

As Members.—Percy George Hamnell Boswell, Ionel I. Gardescu, William Ladislas Gomory, Eric Stanley Hillman, Edward Alfred Hunting, Arthur John Wright.

As Associate Members.—Roland Edwards Hales, Harold Leslie Lyne, James Ness Rodger.

As Transference to Associate Member.—Herbert Richard Lovely.

As Student.—Laurence George Melville Roberts.

As Associates.—Thomas Moore Hickman, John Arthur Reed Potter.

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DECENNIAL INDEX, 1914 to 1924.

The complete index to the first ten volumes of the Journal of the Institution contains some 10,000 references to subjects and localities.

Price: 7s. 6d. net.

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THE PETROLEUM INDUSTRY.

A brief survey of the Technology of Petroleum based upon a Course of Lectures given by Members of the Institution of Petroleum Technologists at the Petroleum Exhibition, Crystal Palace, 1920.

This work will be found of value to students and those desirous of obtaining an elementary knowledge of the Technology of Petroleum.

A few remaining copies for disposal at **2s. 6d.**

All the above to be obtained from the office of the Institution,

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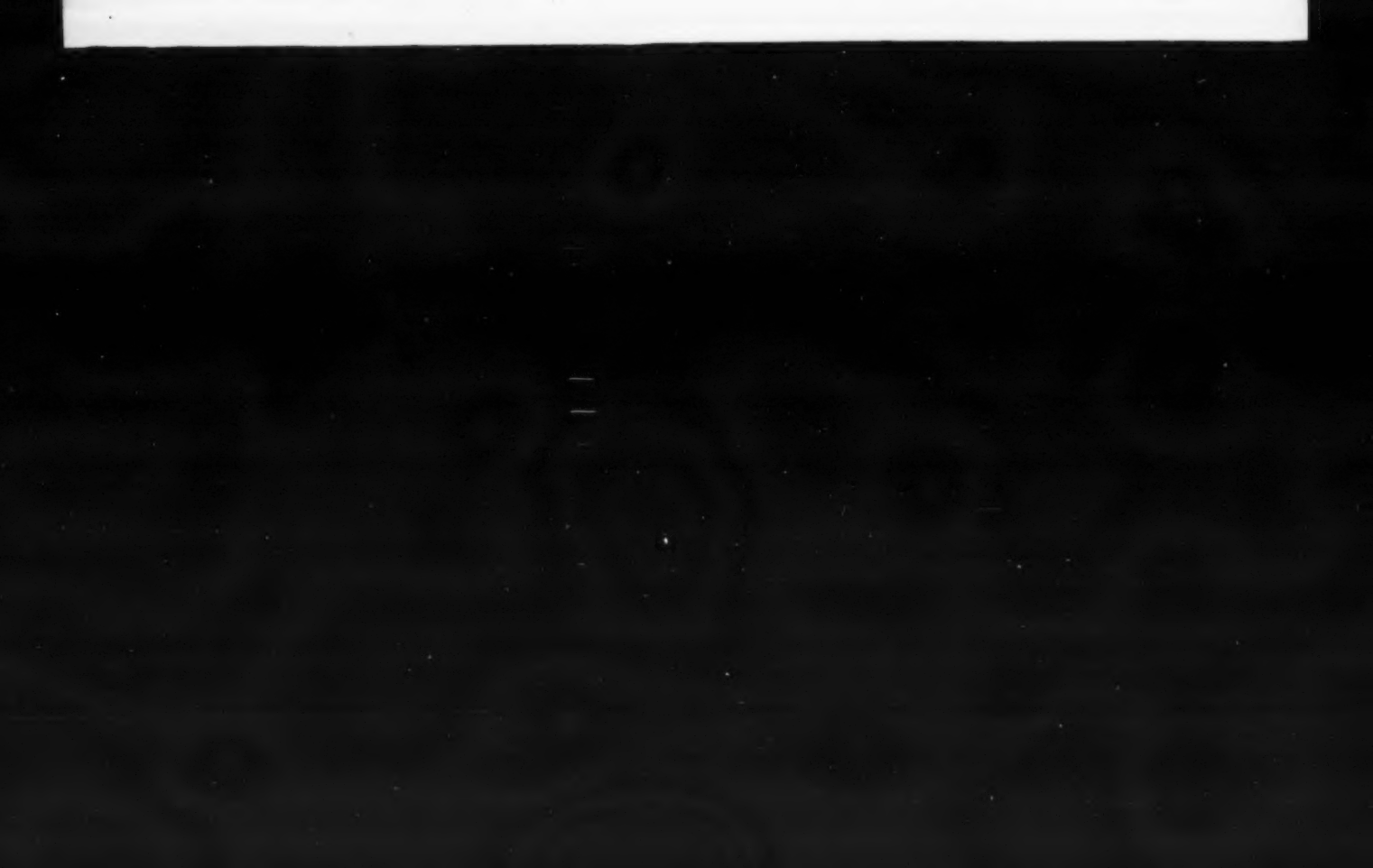

WORLD POWER CONFERENCE.

THE Second Plenary Meeting of the World Power Conference was held in Berlin from June 16th to 25th, 1930, and the following papers submitted by the Institution of Petroleum Technologists were read on June 19th :—

Methods of Utilising, for Power Purposes, the Various Petroleum Residuals and By-Products. By A. E. Dunstan, D.Sc., F.I.C., F.C.S.

The Economic Aspect of the Future Supplies of Diesel Fuel Oil in Connection with the Development of the Diesel Engine. By J. Kewley, M.A., F.I.C., F.C.S., M.I.Chem.E.

Methods of Utilising, for Power Purposes, the Various Petroleum Residuals and By-Products.

By A. E. DUNSTAN, D.Sc., F.I.C., F.C.S. (President).

The chief refinery by-products are :—

1. Acid sludge.
2. Petroleum coke.
3. Asphalt residues (not suitable for normal use).
4. Waste gases.

The problem of the utilisation of refinery by- and waste-products has only attained real prominence in the last decade, and is due to economic factors.

Before this time the by-products which are now discussed were disposed of in the simplest possible manner.

1. Acid sludge produced by the sulphuric acid treatment of lubricating oils and kerosine has been a refining difficulty since the inception of the industry owing to the extreme difficulty in dealing with the large quantities produced and the highly corrosive nature of the material.

Before economic factors made the utilisation of this waste product almost a necessity in helping to reduce general refining costs the problem was simply that of disposal.

The chief methods used to dispose of it were the dumping of it in pits where it accumulated, or emptying of it into rivers, streams or the sea.

River and water pollution obviously reduces the scope for the last two methods.

2. Petroleum coke is produced by the destructive distillation of petroleum products, and is obtained whenever these products are heated above their decomposition temperatures. The main sources of petroleum coke are coking stills and cracking units.

3. Asphalt residues, that is those particular residues which are not suited to the normal uses of this product, such as bituminous material for road making, etc.

4. Waste gases, obtained in the production and refining of petroleum.

The petroleum industry to-day is continuously striving to reduce production costs, and therefore the utilisation of all products from the refinery is becoming more and more important. It is this change that has caused refiners to investigate the possibilities of the use of these hitherto waste products for a variety of purposes.

Acid Sludge.

This is not a subject on which one can make definite statements, as there are so many variable factors to be considered. To mention a few: the acid sludge is different in every refinery, due (1) to the difference in the oils refined; (2) the concentration of the acid; and (3) to the quantity of acid used. Separate groups of sludge can be differentiated which are materially different in their composition and which are dealt with in different ways. These are:—

1. Sludges obtained from lubricating oils and other heavy petroleum distillates.
2. Sludges obtained from benzines and kerosines.

There are in addition sludges produced by other refining methods. Furthermore, there are very obviously at least two general lines to work on in attempting to utilise this product, *i.e.*:—

A. *Recovering the acid from the sludge and reconcentration.*

B. *Finding a use for the acid sludge as produced.*

Both of these basic lines of attack have received considerable attention in the past and both are in extensive and growing use to-day.

Historical.

It is necessary to go a long way back into the history of refining to get the first indication of the commencement of the long struggle with the product. Suffice it to say that in 1859 the subject was of sufficient importance for Henry Pemberton to take out a patent (U.S.P. 24,952) for the treatment of acid sludge. The process consisted of:—

1. A preliminary heating to obtain a separation of the free sour oil.
2. Agitation of the acid-sludge residue with hot water and steam.
3. Separation of weak acid and tar.
4. Recovery of the weak acid by evaporation in pans.

It is of interest to note that this patent, though so old, has been the basis of a very large proportion of the patents which have followed it on this subject.

Bower, in 1880, recovered sulphuric acid by washing the sludge with water in covered tanks and mechanically separating the acid solution from the carbonaceous matter and oily ingredients. Breinig in 1884, mixed with the sludge a soap compound adapted to unite with the tar and separated the free acid from the tarry mass. J. L. Gray, in 1909, claimed the production of pitch and asphalt from petroleum sludge by digestion with water, steam, or dilute acid recovered from the sludge, until the major portion of the acid had been recovered. The tar, comparatively free from acid, was heated with a steam spray until the mass was converted into pitch. Another of Gray's patents covered a process in which the acid sludge was digested with water, air and steam, until the light constituents rose to the top. These were drawn off, and the digestion continued. A heavy residuum was drawn off from the bottom of the separator, and the weak acid finally separated.

Schildhaus and Condra, in 1910, heated acid sludge to 200 to 300° C. (392 to 572° F.), and at the same time introduced air into the retort at about the same temperature. The liquid hydrocarbons were distilled and condensed, and the gases, consisting largely of sulphur dioxide, were washed first with heavy hydrocarbon oil and finally with sulphuric acid.

Van Tienen, in 1911, appears to have been among the earlier inventors making use of both heat and pressure for sludge separation. He recovered hydrocarbons and sulphuric acid from sludge by mixing sufficient water with it to dilute the acid to 52° Bé, and heating the mixture to a temperature of 140 to 165° C. (284 to 329° F.) at a pressure of about 100 lb./sq. in. The liquid was separated into two layers, one containing sulphuric acid and the other containing tar.

Early refinery practice, and the majority of the earlier patents dealt only with the acid separation from the sludge, few of them covered the reconcentration of the acid.

It is of interest to note, however, that Loftus, in 1864, and Penissant, in 1878, described methods for concentrating the separated acid.

Gronsilliers, in 1888, added sodium sulphate to the separated acid and the bisulphate was preciptated by boiling and evaporating. The precipitate was dried and the acid recovered by heating at a moderate red heat. Waring and Breckenridge mixed about 4 per cent. of sodium nitrate with sludge acid at a temperature between 60 and 180° F. (15·5 to 82·2° C.) to purify it and permit the recovery of the sulphuric acid. A foreign patent of interest is that of the

Steaua Romana Petroleum G.m.b.H., in which the separated black acid was allowed to flow continuously into pure, boiling, concentrated sulphuric acid in the presence of an oxidising current of air, the evolved acid vapours then being condensed and reconcentrated in standard apparatus.

1. *Acid Separation and Reconcentration.*—When it is realised that the weak separated acid can now be concentrated to 61 to 62 gravity on a commercial scale at a cost of less than $5·00 per ton, it is clear that recovery of the acid from the sludge is important.

Unfortunately there are several factors which the refiner meets in attempting to use this method, the chief of which is corrosion, which will be dealt with in greater detail later; further, the acid sludge produced is generally viscous, causing considerable difficulty in separating the sludge and water into layers. The acid cannot in the majority of cases be removed from the sludge except by repeated boiling with water; it is then obtained in such a state of dilution which makes its recovery not the simple matter that might be indicated by the above.

In the first two decades of this century the common practice in sludge acid concentration consisted in concentrating to 60° Bé in lead pans, and finishing to 66° Bé in cast iron pans or glass retorts. The lead concentrating pans commonly employed varied considerably in size in the different plants. According to Day, units 5 ft. wide by 50 ft. long and 10 in. deep, as well as a series of shorter pans of the same width (15 to 20 ft. long) were not uncommon. Such pans were generally constructed of 10 lb. chemical lead, and supported by perforated cast-iron plates laid over the furnace flues. Heat for concentration was frequently supplied by combustion of the separated oil.

The acid left the last compartment of the pan, or the last pan of the series at about 60 to 62° Bé, and passed to a series of two cast iron pans, or "stills," generally about 4 ft. by 8 ft. by 10 in. deep, provided with hoods lined with acid-resisting material, leaving the end pan at a temperature of about 450° F. (232·2° C.) and a gravity of about 66° Bé. The vapours were usually condensed in a scrubber and the weak acid returned to the system. Corrosion makes the life of these coatings very short, averaging in one western plant about six weeks, and failure of the pans frequently results in the loss of appreciable percentages of acid.

Slight improvement in this matter was obtained by passing air through the acid; also by the use of glass and silica, and by substituting cascade systems for the pans. The last decade has seen a great decline in this method of acid sludge concentration, and though there are probably many such plants still in use, corrosion is too great a factor to encourage their more extensive use.

In the "Chemico" process a mixture of hot air and flue gases are passed through the acid to be concentrated and a considerably lower temperature can be used than that required for the pan concentration method.

Advantages claimed are that heat transfer is better, fuel costs being correspondingly lower, operating costs including fuel, labour, general expenses and repairs, losses and royalty, is said to be fully 50 per cent. less than with the pan and still system.

Another method of concentration which has come to the fore considerably in recent years in America is the Simonson-Mantius process, which is based on vacuum distillation, with its known advantages.

A still more recent development is the Geyser system. This process resembles the Chemico process in that hot flue gases are used to supply the heat needed for evaporation of the water, but differs from it in that the evaporation is accomplished by blowing the flue gases across the surface of the liquid, which is kept in a violent state of ebullition by means of an independent stream of air.

The Chemico and Vacuum processes are two-stage systems in which the first concentration is to 60 to 62° Bé, and the final concentration to 66° Bé. The Geyser system is a one-stage process.

These are general methods but as has been mentioned, the variety of the sludges produced at various refineries necessitates special processes or alterations.

For example acid sludge from cylinder stock is in many cases not easily separated in the ordinary type of "cooking" kettle. The sludge being heavier than the water sinks to the bottom, and cannot be completely agitated with the water. Dependent on the nature of the acid sludge a large or small number of lumps are left, and in some cases there is unavoidable caking.

The water used in the process hydrolyzes the sulphonates and removes the acid from the surface of the lumps or cakes, thus "coking" the surface. In this manner no separation takes place in the lumps or cake.

The method of separating acid sludges under high temperatures and pressures cannot be used with most cylinder stock sludges as by this process the sludge is simply coked hard to a non-fusible mass, and owing to it being heavier than the separated acid cannot be withdrawn from the separator.

To illustrate the individual methods used and necessary at different refineries with different requirements, there follows a short account of the procedure at one American refinery producing approximately 100 tons of acid sludge per day.

The initial sludge is termed green sludge, owing to the fact that it contains sufficient oil to give it a green cast. The green sludge is separated in lead lined open cooking kettles. The success of the subsequent operations at this refinery depend first upon the use of light oil acid sludge with water to give a weak acid of sufficient gravity to float the green sludge at the start of the separation; and second, upon the use of sufficient acid oil from a previous treat, along with some fresh slop oil or gas oil, to extract the oil content of the sludge.

The light oil sludge is that resulting from the treating of Dubbs Pressure Distillate and is about 45° Bé gravity (heavy) and contains about 58 per cent. sulphuric acid. The solvent oil used may be any oil having a gravity sufficiently high to obtain separation.

The steps in the separation of the cylinder stock sludge are :—

1. 120 barrels of acid oil or " Top " oil are left in the kettle from the previous run, to act as a solvent to thin the heavy green sludge as it is drawn into the kettle.

2. Thirty five barrels of light oil sludge are charged to the kettle.

3. About 100 barrels of hot water are added, the quantity being sufficient to separate the light oil sludge into a weak acid of 24° Bé (heavy) gravity which is heavy enough to float the green sludge. This step completes the preparation of the kettle for the receipt of the green sludge. The preliminary steps require about one hour.

4. The green sludge is then gravitated from the agitator into the kettle. A batch uses 235 barrels of sludge. The draw takes about two hours, and during this period live steam is used in the kettle to agitate and heat the mass.

5. About 175 barrels of solvent oil are then pumped in, about one hour being required.

6. An additional 85 barrels of hot water are added over a period of one hour. During all of this time, the kettle is cooking with steam, the total cooking time being four to four and one-half hours.

7. After the final water is added, the steam is cut off and the contents of the kettle allowed to settle for three hours. Three layers are formed, a bottom layer of about 150 barrels of 24° Bé acid, a middle layer of so-called " wet sludge " and a top layer of about 400 barrels of top oil. The acid layer is drawn off.

8. The kettle is again cooked up with live steam, the contents being thoroughly agitated for ten minutes. The mass is allowed to settle for one-and-a-half hours and a second acid draw is made, 70 to 90 barrels being obtained. If the separation is not good, several re-cookings may be necessary.

9. With all the weak acid separated and drawn, the middle " wet sludge " layer is drawn to the acid pit where the remaining weak acid can drain off.

10. About 285 barrels of top oil are pumped out, leaving 129 barrels in for the next run.

A typical run on a cylinder stock sludge kettle is outlined in Table I. giving the actual acid and oil recovered.

TABLE 1.

Charge.	Kettle No. 2. Barrels.	Gravity.	Batch No. 300. Acid content.
Top oil	120	21·5° A.P.I.	
Light oil sludge.. ..	35	50·1° Bé.	12,460 lb.
Green sludge	250		19,849 „
Solvent oil	175		
Water	185		
Total acid in charge			32,309 lb.
Recovered.			
First weak acid ..	147	24·5° Bé.	17,520 lb.
Second weak acid ..	77	24·5° Bé.	9,310 „
Total acid reclaimed			26,830 lb.
Per cent. acid reclaimed			83%
Wet sludge	111	(6·4% acid)	2,675 lb.
		Carried fwd.	29,505 lb.
Fuel oil	285	21·7° A.P.I.	180 „
Top oil (left in)	120	21·7° A.P.I.	
Total acid accounted for			29,685 lb.
Per cent. acid accounted for			92%

The weak acid is concentrated, in a vacuum evaporator system, to 63 to 64·3° Bé. This is blended with purchased fuming acid (104 per cent. H_2SO_4) to make 93·5 per cent. acid.

This process with its length of detail should serve to indicate the individual methods necessary and employed to meet individual refinery cases if dealing with this subject, and it should be noted that this refinery process is rather different from those that have been already referred to; it is derived from the process formulated almost simultaneously by Smitz and Seidenschur, who stated that the organic constituents of ordinary acid sludge, which are only slightly soluble in benzine and similar solvents, are easily absorbed by solvents such as the middle and heavy oils obtained from the distillation of crudes and tars. The addition of these oils as solvents enables them to unite with the organic bodies present and separates out the acid in a very much greater strength than would be obtained by water separation.

ACID SLUDGE OBTAINED FROM THE REFINING OF KEROSINES AND SIMILAR LIGHT DISTILLATES WITH SULPHURIC ACID.

This sludge is visibly different from the sludge obtained from refining lubricating oils insomuch as it is a much lighter, more fluid

liquid, usually black in appearance, of a "tarish" nature and with a pungent acid smell. On dilution with water it separates fairly easily into several layers. The lower is composed of acid of dark colour, this latter characteristic being caused by the organic substances held in it. The upper layer consists of a liquid resinous substance which is the polymerised and sulphonated product of the mixture of the original spirit and sulphuric acid. There is also a definite middle layer of sulphuric acid esters and sulphonic acids which can be removed by water washing. Further, there are in many cases intermediate layers between these definite layers.

It will be seen that the sulphuric acid can be reasonably easily removed by the addition of water, and on separation can then of course be reconcentrated by evaporation.

The word "reasonably" is used because the acid separated by water contains in solution, besides sulphonic acids and salts of nitrogenous base, a considerable amount of tarry bases, which on the evaporation of the acid separate out and must be continually removed.

This separation is never complete, a quantity of tarry substances is, at the conclusion of the separation, left in the solution, usually serving to give the acid a dark colour. Oxidation of these compounds naturally occurs in the concentration of the acid accompanied by the liberation of sulphur dioxide.

Actually, the acid, on initial separation, has to be further diluted with water a number of times and after each dilution a further deposition of tarry substances will occur.

The resultant dilute acid is always dark, usually black in fact, and in this form finds but little use in the hands of the refiner.

It can, however, be made pure if the black acid is concentrated to a fairly high strength and then mixed with pure sulphuric acid, allowed to flow into heating vessels in the presence of a flow of air and subjected to a temperature of round 300°.

Little use has so far been found for the organic part of the acid sludge. One use and least of interest is that of using this tarry substance after treatment for the production of artificial asphalt, and when this operation is made without the use of air an elastic substance is formed.

The sulphonic acids which have been referred to are in some cases themselves extracted and used in a variety of industrial purposes.

Utilization of the Acid Sludge as it is Produced.

The production of acid sludge is increasing, and will probably further increase. The methods of utilization that have been mentioned do not absorb in the majority of cases anything like the

amount produced. For example, one well-known American refiner asked how much sludge he had on stock gave his answer in acres.

Most of the known methods of utilization necessitate movement of the sludge, here, as has been previously remarked, corrosion is a very big and often limiting factor. Against the value of the final by-product obtained must be offset the prime cost and cost of repairs to conveying machinery and labour involved.

There has only been one efficient form of utilization found in these circumstances, and that is use as fuel.

The acid sludge as produced cannot naturally be used as direct fuel owing to its high acid content. It can however be mixed in varying proportion with fuel oil and then in this fluxed state is a reasonably satisfactory burning fuel though it suffers from many disadvantages which will be dealt with at greater length later.

Here again there is a wide variance in method used in different refineries, though basically they are the same.

As every refinery utilizes heat in varying amount, the ability to use this hitherto waste product as a fuel is an economic factor of considerable importance. The disadvantages that offset at first sight the apparent economic advantages are firstly corrosion, secondly unless the sludge can be used with the minimum of movement it is necessary to neutralise it to cut down corrosion losses. If, however, neutralisation is necessary it naturally increases the cost as agitators or mixers are necessary and furthermore the resultant fuel product has a considerably higher ash content and is therefore not so satisfactory. When the acid sludge is fluxed direct with fuel oil or other distillate it is a reasonably good fuel particularly so owing to its low ash content.

One or two refinery processes in brief should be of interest.

At one American refinery the Bright Stock acid tar is drawn off, strained and then pumped to the top of the mixing tanks. Here it is mixed with fuel oil and heated by coils to about 100° F., is afterwards agitated in a specially designed plant, made to cover the variance in the nature of the sludge received, *i.e.*, from a mobile liquid in summer to that of a very viscous product in winter. The mixture is then withdrawn from the tank and pumped to a sloping supply tank, heated underneath by steam coils. This last tank delivers it at a temperature of 100° F. to the air-oil burning system used, the flow being regulated by a control valve.

Another refinery process is as follows: Two kettles which were formerly used as Acid Separators in an acid recovery system, were rehabilitated for use in the sludge fluxing process. They have a capacity of 250 barrels, are 26 ft. 6 in. in diameter at the top and taper to 22 ft. 6 in. at a distance 9 ft. 6 in. below the top. From this point a 30° cone serves as the bottom of the kettle. The

kettles are equipped with coils through which steam or air can be admitted for purposes of agitation. Steam and air may also be admitted through a suction line. The sludge acid from the cylinder stock is divided into two equal dumps, and two batches of sludge are fluxed in separate kettles. To start the process a quantity of 13 to 15 gravity fuel oil, equal to the amount of sludge, is pumped into the kettle and agitation started by admitting air through the suction line entering the bottom of the kettle.

Practice has shown that the temperature of the fuel oil should not exceed 120° F. (49° C.) to obtain best results. The cylinder stock is treated at a temperature of 160° F. (71° C.) and the sludge formed from the first dump of acid is pumped into the kettle through strainers at the top of the kettle. These strainers consist of short 12-in. pipe with welded bottom plates which are perforated with ¼-in. holes. They are equipped with steam connections so that they may be steamed in case they become plugged up. The strainers aid in breaking up and disintegrating the sludge mass. While the sludge is being pumped into the kettle the contents are kept well agitated by means of air introduced at the bottom of the kettle. This eliminates the possibility of the sludge falling to the bottom of the kettle and forming a hard mass, which would be difficult to work off. When all the sludge, about 125 barrels, has been transferred to the kettle, air is introduced through a line extending over the top and into coils which are installed on the inside walls of the kettle. Introduction of air through these coils gives the contents of the kettle the necessary agitation and during this agitation the air is cut off at the bottom inlet.

This air agitation is kept up for a period of five to ten minutes, at which time a pump takes suction from the bottom of the kettle and discharges into it again through the strainers. During this circulation operation the temperature of the oil is raised to 180 to 200° F. (82 to 93° C.) by means of closed steam coils. This circulation and agitation is continued until the batch is completed or when all the sludge has dissolved into the Fuel Oil giving a smooth homogenous product.

If the sludge should begin se tling on the bottom of the kettle it was found that it could be worked back into the oil by the introduction of steam through the suction line at the bottom of the kettle.

There are several factors which determine the ease and success with which a batch of sludge is fluxed off. If a higher temperature than 160° F. (71° C.) is used for acid treating the sludge will be hard and gritty and will form a harder coke. Difficulties are also encountered when trying to disintegrate such a hard sludge in the fuel oil. If the correct temperature is used for acid treating and the

temperature of the Fuel Oil is too high at the beginning of the fluxing operation, the sludge will coke and harden when it comes in contact with the hot oil and will cause difficulty in handling.

Sludge from the second acid dump is handled differently in that a greater percentage of fuel oil is used to work it off. 125 barrels of fuel oil are used to about 40 barrels of sludge. This is necessary because of the hardness of the second sludge as compared to the first and the greater difficulty in disintegrating and dissolving it in the fuel oil.

The time required for completing a batch of sludge varies from 1 to 4 hours depending upon the nature of the sludge.

Burning of the Sludge Fuel.

When the sludge fuel is judged to be of satisfactory quality it is pumped into a fuel storage tank at the still battery. The oil is kept agitated with a small quantity of live steam and the tank is equipped with a pump which takes suction on the bottom and discharges back through the top, thus keeping the fuel oil in constant agitation and preventing the formation of any solids which would tend to settle out. The fuel oil is fed by gravity to injector type oil burners which have been installed under all stills.

Quality of Fuel.

Average tests on a completed batch of sludge fuel are :—

Gravity	10·3° Bé.
Ash	0·15%
Acidity	1·0 %
B.Th.U. per lb.	16,800

Sludge fuel as manufactured in the above manner is found to be a satisfactory fuel for heating the shell and pipe stills at the refinery. Although it would appear that there would be some disadvantage in the use of such a fuel, no difficulty has been encountered. The small amount of ash in the fuel is carried out with the waste gases and none of it has accumulated on the still bottoms or tubes. This eliminates any objection that a deposit would build up on the exposed surfaces and eventually cause local overheating.

These examples of different refinery practice should serve to indicate that there is a definite economical use for acid sludge as a cheap, yet under carefully devised conditions, efficient fuel.

Burning Processes for the Sludge.

There are in general two main types of burners.

The rotary type of burner is little more than a fuel incinerator. In many refinery cases where the production of acid sludge is greater

than the amount of sludge that can be utilised by other methods, this type of burner is used to dispose of the surplus.

In size they vary greatly, being built to suit individual refinery requirements, 400 lb./h. is the largest size the author is aware of, but this figure is probably exceeded in many cases.

The other type of burner are varieties of air-oil injection burners for heating stills and other plant.

A little greater detail on these methods of combustion should be of value.

The rotary type of burner as has been stated is little more than an incinerator, it will handle with ease any waste fuel from refineries such as the acid sludge as produced, the wet sludge from the cooking kettles, dried sludge from the sludge dumps, asphaltic residues, and, if necessary, acid sludge fuel mixture. The burner is usually a form of rotary kiln, generally in a horizontal position.

An American rotary burner which will serve to illustrate the type admirably is the Duncan. This is a horizontal rotary retort of varying capacity, rotated at roughly 20 revolutions per hour. The rear end is equipped with a fuel hopper and a variable speed screw conveyor which feeds the fuel into the burner at the desired speed. The forward end of the burner is restricted in size to enable it to hold the solid fuel in the kiln until entirely consumed. The metallic portions of the burner are made of a special cast iron to reduce corrosion losses.

The sludge is fed through the screw conveyor and falls on to the incandescent fuel bed or burner lining where it almost instantly ignites. The volatile portions are vaporized and burned as gases and vapours in the early part of the cycle, and the residue is coked. The rotation of the burner keeps the fuel agitated, continually bringing fresh fuel against the heated lining where it is cracked to gas and coke.

When burning plastic or semi-fluid material, the fuel softens and tends to remain in mass on the bottom of the burner. High pressure jets of air or steam are directed against the plastic mass to agitate it until such time as the fuel is cracked to gas and coke by the heat of the kiln walls. Experience has shown that steam functions equally as well as compressed air for this purpose. Air from a forced draft is admitted around the screw conveyor, and passes through a series of vanes which give it a rotary motion. This causes the air to hug the inside of the burner is such a way as to be brought in close contact with the fuel bed and any liquid fuel which may be carried up on the sides of the burner. The air admitted to the upper part of the burner supports the combustion of the gases. Tuyeres located below the fuel line furnish air for the combustion of the solids.

The rotation of the burner rolls the fuel mass over and over, advances it towards the front of the burner and breaks up the coke. The forced draft picks up the small coke particles and ash and carries them into the boiler combustion space. Sufficient primary air may be used to practically complete the combustion, or if preferred, the burner can be operated as a gas producer and secondary air used in the furnace proper to complete the combustion. The wet sludge is picked up from the storage pit by means of a monorail crane and clam-shell bucket, and is charged into a storage hopper located directly behind the burner. A variable speed, cast iron drag chain conveyor breaks the sludge into small lumps and conveys it from the storage hopper to the small feed hopper on the burner proper. The conveyor is controlled by a variable peed motor at such a rate as to keep the feed hopper about half full of fuel. The sludge is charged from the feed hopper into the burner by means of the screw conveyor at whatever rate that is desired. Sufficient gas is burned at all times to insure ignition of the heavy fuel. This usually requires about 6000 cu. ft./h.

The air oil injection burners are of varying nature. In general, however, they are used when the fuel is used for heating purposes, pipe stills, etc. These burners operate on closed furnaces either injecting the fuel under high pressure in the form of a mist from which it is suitably ignited to the fire space under the still tubes, or along tubes in parallel to the still tubes, these tubes being perforated with small holes, the fuel flowing out in thin streams from which it is suitably ignited. There is one great difficulty in burning the fuel and that is once again corrosion.

In heating stills with air oil burners using acid sludge fuel mixtures corrosion is a serious trouble.

The operating temperatures are very obviously too high to allow any moisture deposition and the corrosion must take place during the periods the still is not in use when they would have condensed moisture on them. When boilers are shut down periodically and the tubes flushed with water heavy condensation on the outside very naturally takes place.

On heating up again the SO_2 and SO_3 fumes from fuel form with moisture sulphurous and sulphuric acid, which readily attacks the iron.

Corrosion is heaviest on the lowest tubes as the moisture drips on to these from those above.

The remedy lies in the abolition of moisture.

In some cases refiners use caustic soda, or other equally strong alkaline material in admixture with the sludge, in order to partially neutralize the acidity, but as a very large quantity would be required, and considering the cost of the neutralizing agent,

this is hardly worth while when the raw acid sludge can be satisfactorily burnt, if the necessary precautions are taken.

At a large English refinery, however, using the calcium hypochlorite process of refining a portion and the residue of the lime sludge is used to neutralize the light acid sludge produced in the treatment of light distillates, kerosines, etc.

The heavier sludge from lubricating oil and bright stock treatment is water washed to separate a quantity of the oil which is then used as a refinery fuel.

The residue is disposed of in the most convenient way in sludge ponds.

Asphalt as a Refinery By-Product Used as a Fuel.

This is not a general refinery by-product and is obviously entirely dependent on the nature of the crude used.

Asphaltic petroleum residue of good quality is normally regarded as a valuable petroleum product and for road-making purposes it invariably commands a higher price than that obtained for fuel oil. Again, for other more specialised purposes such as waterproofing, electrical insulation and the manufacture of roofing felt, good prices can usually be obtained. Where, however, the asphaltic residue produced is not considered suitable for the present known applications, this relatively valuable material must of necessity be regarded as a refinery by-product, and unless it is suitable for the production of heavy lubricating oils, its only use is as a low-class boiler fuel. On the other hand, many asphaltic residues unsuitable for road construction, etc., could in any case only be regarded as by-products. Their unsuitability for road purposes may be due to a variety of causes, such as excessive hardness, too high a percentage of paraffin wax causing a deficiency in ductility, incorrect relationship between the constituents of the asphalt, etc.

The combustion of asphalt under boilers and in furnaces is a matter requiring a certain amount of forethought and extra expense, but providing that precautions for maintaining the material in a liquid form and for utilising a suitable firebox are taken, the problem presents no unsurmountable difficulties. In many refineries, asphalt is being burnt under boilers and cracking plants, but usually a parallel liquid fuel burning system is provided as a " stand by." Asphalts of melting points up to 80° C. (176° F.) have been burnt successfully without cutting them back with liquid fuel, and it is probably that material of even higher melting point could be burnt using specialised apparatus. In one type of plant brought to the authors' notice the heated liquid asphalt was circulated through a ring line from which the burners were supplied. The

ring line was fitted internally with an asphalt heater of the tubular type, the first part of it with branch lines to the burner being 3 in. in diameter. The ring line was then reduced to 2½ in. and later to 2 in., and was supplied with various expansion bends. The branch lines were constructed of extra heavy copper tubing. Two circulating pumps in duplicate were provided and in the event of a breakdown on both pumps, the system could be flushed out by means of the pumps of the fuel oil system.

When burning high melting point material it was stated that a rather heavy deposit of coke formed on the furnace floors and caused irregular firing. This was due to the combustion space being too small, but by deepening the furnaces to about 1 ft. 8 in. below the centre of the burners, a considerable improvement was obtained, so much so indeed that it was found unnecessary to use compressed air to accelerate combustion, as had been done previously. Coking of the tips of the burners occurred to a greater extent than when fuel oil was used, but this trouble was not considered to be serious. The asphalt was heated to about 300° C. (572° F.) in the heater and returned to the tank with a temperature of approximately 200° C. (392° F.), the discharge pressure being about 11 atmosphere.

Where coal fines or low quality coal slack is available certain types of asphaltic residue can be used as a binder to form the powdery material into briquettes. Owing to the relatively high calorific value of the asphalt addition the resultant solid fuel compares very favourably with high-grade coal as regards heat value, but in the case of the coal slack briquettes, their relatively high ash content is in many cases a definite drawback.

It will be realised therefore that asphaltic residues, although not being by any means an ideal liquid fuel, can at times be used to considerable advantage, particularly where storage space for asphaltic materials is limited and where the whole throughout of a given crude oil is being refined to give a complete range of fully refined products—*e.g.*, motor spirit to lubricating oils.

Petroleum Coke.

Petroleum coke is a waste product from the destructive distillation of petroleum products at temperature above their decomposition temperature. It is in appearance very varied, ranging from a dirty sooty dust, fines, cakes, to normal coke appearance.

Proximate analysis.	Petroleum coke. %	Anthracite coal. %	Bituminous coal. %	Lignite. %
Moisture ..	1·40	4·2	2·9	37·1
Volatiles ..	12·03	4·5	34·3	26·9
Fixed carbon ..	85·84	79·0	55·6	26·9
Ash	0·84	11·6	5·8	7·8
B.Th.U./lb. ..	15,293	12,485	13,630	6,500

The extremely low ash content of petroleum coke will be readily noticed and this is a large advantage when considering the question of residue.

It is far superior in thermal value and is low in volatiles ; this is important, as it indicates the smoke-producing qualities.

These properties indicate its use as a domestic and general fuel. Unfortunately, as produced from the still, it offers many transport and utilization difficulties, due to its large content of powdery matter and general friability.

There are several processes for briquetting it, but these will be dealt with later.

Production Sources.

The last decade has seen the rise of the cracking and coking industries. Petroleum coke is produced from both these processes in large quantities, and the vast expansion of these industries has increased the production of this by-product to a very great extent. Last year about one million tons were produced in the U.S.A.

Cracking.

In the early part of this century the most important light fraction from petroleum was kerosine, used for burning and illuminating purposes. The advent of the motor car brought a new product rapidly to the fore, *i.e.*, motor spirit. The rapid development of the automobile industry soon changed the position, and in a few years motor spirit was the largest and most paying product from petroleum.

The development of the car caused greater demand for spirit, the increase in the efficiency of cars led to more and more exacting standards for petrol.

The refiner, until a period ending just after the recent war, could meet his petrol requirements quite easily from his crude production. The demand, however, for petrol rose to such an extent that the refiner was faced with another problem. Either he must increase his production of crude above his necessary figure for meeting markets with the heavier distillates, or he must endeavour to increase his yield of petrol from his normal refining method. On the straightforward distillation process up to then in use he was obtaining round about 17 to 20 per cent. of his crude as a motor spirit. Excess production of crude to enable him to meet the greater demand of petrol would in a very short while have meant impossible storage conditions.

The markets, unfortunately, for the heavier fractions had increased in nothing like the same proportion to that of the lighter.

What was therefore more natural than he should endeavour to obtain an increased yield of lighter distillates than he was then obtaining.

Research therefore developed the cracking industry.

This has resulted in the refiner being able to compete with the growing demand, and the amount of spirit suitable for use as petrol now obtained from the crude is round 35 per cent.

However, the advantages of this process are to a certain extent offset by the fact that the continued heating, besides breaking down the molecular structure of the charge and so forming lighter distillates, also produces polymerisation, which is evidenced by deposition of the so-called petroleum coke, usually a hard porous shining substance composed probably of hydrocarbons of high molecular weight of polyclic form and usually low in hydrogen content.

Utilization of Petroleum Coke.

In the majority of refineries no immediate use for the coke could be found; it was therefore dumped, and there arose again the question of storage space, almost acreage, as was the case with acid sludge.

Quite a large percentage of refineries were, owing to lack of space, unable to dispose of it by dumping, and it is their experiences in the utilization of this product that is of particular interest.

The most important use yet found is as its use as an ashless, almost smokeless, rich fuel. A ton of good petroleum coke produces less than 20 lb. of ash, which also is usually of non-clinkering nature. The coke requires less draught than ordinary coke or coal, it is consequently slower burning, more economical and generally requires less agitation. These manifold advantages give it a value to many industries almost on a par with that of anthracite.

Against these advantages it must be stated that the transportation of the coke is not usually an easy matter. On production it has a very large content of fines and soot, and the larger size coke has a tendency to turn very quickly to fines and dust; therefore, when lengthy transportation is necessary then some form of treatment must be given it, which raises the cost. Owing to its very small ash production it cannot be used alone for firing chain grates and stokers. The absence of the protective layer of ashes makes the heat on the grates much greater, and in these circumstances the grates very quickly burn out. It is therefore necessary to mix the coke with coal, equal quantities of these two fuels is said to be roughly the economic limit, and in this proportion there is very little evolution of smoke.

Generally, however, any kind of furnace, including those hand-fed, can utilize petroleum coke as a fuel, provided there is a protective layer of bricks on the bars or grates.

It has been used in the smaller railroad engines in the southern United States with considerable success. Alterations to the design or layout of the fireboxes were negligible and running costs, as compared with the fuel oil previously used, were between 15 and 25 per cent. lower.

There are a number of other minor uses for this coke. They are minor only in respect to quantity, as the products they produce usually obtain a considerably higher price than would the coke itself if used as fuel. These uses, which include the production of almost pure carbon for the production of graphite, electrodes, crucibles, pencils, dry cell batteries, briquettes, etc., are governed entirely by the nature of the coke produced.

There has so far been mentioned only the cracking process as a source of petroleum coke production. There is, however, one other very large source of production, and that is from the carbonization industry. As this is now a separate industry and is hardly a refinery by-product the utilization of the coke produced from this source will not be dealt with.

Quite early American manufacturers found use for this product from cracking processes as a fuel, and when the refineries found there was a plentiful and growing demand in towns close to their refinery they naturally started to exploit the supplying towns remote from their installations, more particularly those not in or near fuel-producing areas.

The following table, showing the consumption of petroleum coke in detail for the year 1928 in America, indicates the relative importance of the various uses.

Consumption of Petroleum Coke, by Uses, 1928.

Type of consumption.	Short tons.
By petroleum refineries as fuel	550,000
As domestic fuel for house heating	220,000
As pulverized fuel in various industries	154,600
Shipments to foreign countries	144,100
Manufacture of electrodes and carbon products	105,200
Gas-making and generation of electric power	98,400
Lead and zinc smelters	25,800
Pigments, carbides, lime, etc.	19,600
Experiments and miscellaneous heating	6,500
Total	1,324,200

It will be noticed that the refineries consume over 40 per cent of the total consumption themselves. Some refineries burn this coke in an admixture with coal for heating stills, etc., others pulverize

the coke then mix the pulverized fuel with low-grade fuel oil, acid sludge, fuel oil, etc., and burn it in closed furnaces by means of air oil burners, as has been described.

The second largest use is nominated as that of household heating. Here the nature of the coke is of the utmost importance. The only type of petroleum coke suitable for this use is the larger normal coke-like lumps, the fines and soots are of little use as on a normal grate this fuel would slip through the grate bars. The alternative is to provide a new type of fireplace suitable for its economical combustion until the quality, nature and price of the coke have been firmly established and a plentiful and well-distributed supply arranged. This appears of but little use. The question of price, apart from the preceding, will, of course, be the deciding factor. At the moment the prices ruling for coke in the States is :—

	Per ton
Lumps	$4.50 to $5.00
Still runs	$3.00
Breeze	$2.00

However, if this product can be marketed in a convenient form and at a considerably cheaper price than coal, with a good supply organisation arranged, then it is hard to see any reason why it should not be a success.

The refiner has to a point met the position half way by the production of coke briquettes from his unwanted production of fines and coke soots. This is an interesting development and will receive attention later.

Third on the consumption list is its use as a pulverized fuel in various commercial industries.

The authors understand that the pulverized product is used in some brick plants in admixture with the clay to assist in the burning of the brick and to improve its colour. The coke acts as a reducing agent to the metallic oxides in the clay without leaving any ash minerals in the brick, as is the case when coal is used for the purpose.

It is also on record that it is being used in a big meat packing company. Fruit growers are using it for smudge fires, as it has been found that it does not impair the quality and flavour of the fruit. Wireless manufacturers use it in the production of battery cells. Another use in the pulverized form is in foundries for metal smelting and refining. Cement manufacturers find it of use as a fuel in the production of their product. It is stated that a ton of pulverized petroleum coke is sufficient to manufacture approximately 20 barrels of cement. Then, again, its use as a building heating fuel is obvious; on oil-fired furnaces it can quite easily and profitably be used.

The author has received advice on the stoking of a steamer in the East with low-pressure cracking coke.

The analysis of the coke used was as follows :—

Cal. val. maximum	8.920 cal.
Oil content, soluble in benzol	6·2 %
Sulphur	0·17%
Ash	0·32%

The coke used was damp, as it had been lying out of doors, and about 50 per cent. of it was in the form of coarse powder. It was dropped 12 ft. into the bunkers, from which it suffered no harm. It was first used in a mixture with coal in the proportion of coal to coke = 3 : 2, the coal being of poor quality, with about 30 per cent. ash. This gave satisfactory results. Later, a mixture of 2 : 3 parts of coal and 6 parts of coke, was used ; this gave satisfactory results, and after running 24 hours on this mixture one of the furnaces was stoked with the coke only. The combustion was good, with medium fires. A small portion dropped unburnt from the firebars as these were 1 in. apart. This was put back on the fire again. Later, all furnaces were stoked with the coke. Combustion was good, with practically no smoke, giving plenty of steam. 1·85 lb./i.h.p./h. was used, in comparison with 2·35 lb./i.h.p./h. for coal. The objection that coke takes up too much space, as compared with coal, was therefore overcome by the higher combustion value of the coke. This particular steamer used about 8 tons of the coke in 24 hours, in comparison with 11 tons of coal. On arrival at Singapore firebar bearers were found to be in good condition. The steamer's staff were well satisfied with this coke.

Fifth on the list, the manufacture of electrodes and carbon products, has already been mentioned and the increasing consumption in this line is due to high standard of carbon obtained.

Though these figures and remarks indicate that considerable progress is being made in the utilization of this by-product there is undoubtedly room for further utilization as the following figures will show.

	Coke output. Tons.	Coke stocks. Tons.
January, 1928	103,200	331,300
April, „	109,400	342,100
July, „	127,000	384,900
October, „	125,000	404,400
January, 1929	137,900	403,800
April, „	130,700	444,900
July, „	157,900	563,900
Sept., „	161,200	648,500
21 months' increase	56·2%	95·7%

Briquettes.

As has been stated the refiner in order to find a market for the less marketable portion of the coke, the fines and soot have in many cases solved it by the production of briquettes.

Many processes have been evolved for the formation of briquettes; they all however initially pulverise the coke to a very fine mesh, and then bind it by some low-priced fuel, such as tar, etc.

One most interesting process of double value consists in the first place of crushing and then pulverising the coke to 30 to 60 mesh. An electro magnet then takes out the metallic particles, reducing subsequent wear on plant and making the product cleaner. The product is then mixed hot or cold with refinery acid sludge, 5 to 10 per cent. usually being the amount necessary. By this utilization of acid sludge another market is made for this also wasteful and troublesome product.

The coke and acid sludge are very thoroughly mixed and then fed to any form of briquetting press. A roll type press was selected, producing small pillow-shaped briquettes weighing 3 to 4 ounces. The product now in the form of a briquette would still not stand up to anything in the way of rough treatment. It is accordingly fed on to a conveyor and taken to a roaster or carbonising furnace wherein a temperature of 110 to 450° F. (232° to 593° C.) is maintained according to the product desired.

In this furnace the briquettes receive sufficient heat to drive all or part of the volatile matter off, the sooty fine carbon is disposed of and it is claimed that the product is a clean, metallic-like coke structure. The process also includes for the collection of the volatile matter driven off and its use in the gaseous state as a heating medium for the carbonizing plant.

It is further stated that the briquettes on emission from the furnace are a finished product consisting substantially of pure carbon of exceptionally hard structure and capable of withstanding the most severe handling, yet possessing a sufficiency of volatile matter to enable ready ignition but not enough, however, to prevent the fuel being smokeless.

Waste Gases.

In the refining of petroleum a large quantity of gases are evolved, which in the majority of refineries in the past have been looked upon as waste and have usually been burnt.

Various uses have now been found for this waste product.

In the first place it is in many cases passed through middle oils which absorb part of the gas. The oils are then heated and the absorbed gas is recovered as motor spirit or light distillate. The stripped gas is then passed to the stills and is used under suitable conditions as heating power.

Another use is the cracking of these gases to form various alcohols.

An entirely different type of waste gas is "natural gas." This is, of course, the gas which issues from petroleum wells.

The utilization of this product can only be effected in certain cases, *i.e.*, when the refinery is very close to the actual producing wells and as this is frequently the case in America the matter is of certain interest.

There are two chief methods of utilizing this product.

The first is in the refinery as a fuel, the gas being conveyed by pipe-line to the stills; it is burnt in closed furnaces through suitable burners.

The second use is as a commercial and domestic heating unit.

The last few years have seen an immense stride in America in this form of utilization. Miles of pipe-line have been laid to supply most of the towns in the central and southern states. According to United States Bureau of Mines 1,568,139,000,000 ft. of gas was produced and delivered to consumers in 1928. This figure incidently is an increase of 8 per cent. over the previous year.

In the individual consumption, domestic consumers, of which there are over 4¼ million in the States, used 20 per cent. at an average price of 60·8 cents. per thousand feet.

Of the remainder, approximately half was used for industrial purposes whilst the other half found use in the fields and refineries.

Lastly, natural gas is also stripped to produce a light spirit, which though very wild is used in admixture with normal motor spirit to give this last product a lower boiling range. The extent to which this industry has grown may be gauged by the fact that 200 million gallons were produced in the States in October last.

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The Economic Aspect of the Future Supplies of Diesel Fuel Oil in Connection with the Development of the Diesel Engine.

By J. Kewley, M.A., F.I.C., F.C.S., M.I.Chem.E.
(Vice-President).

In this paper the word "gasoline" is used to designate motor spirits, essence and benzine; the word "distillate-fuels" to designate such fuels as are known as gas oils, solar oils, heavy

kerosines, etc., which are distillates containing little or no residual oil; the word "residual oil" to designate the dark oils resulting as residues from the distillation process. This nomenclature is necessary as oils which are known as furnace or fuel oils in the U.S.A. would be termed gas oils in the U.K. To ensure clarity terms such as petrol, naphtha and benzine are avoided. For similar reasons the two main types of engines are referred to as spark-ignition and compression-ignition.

During its somewhat meteoric career, the petroleum industry has experienced more than one important change of centre of gravity in respect of the products made from the crude. In the early days kerosine or illuminating oil was the all-important product, gasoline and liquid fuel being of little or no importance, the former being indeed a waste product. In those early days, as was natural, every effort was made by the refiner to produce the largest possible yield of kerosine from the available supplies of crude. This, therefore, was made with a long boiling range including as much of the volatile fractions as the statutory limits for flashpoint would allow and as much of the heavy fractions as the methods of refining to a stable product of good colour would permit. With the advent and rapid development of the spark-ignition internal-combustion-engine, the demand for gasoline changed the situation, so that the centre of gravity of the industry swung over to the production of the lighter fractions. The displacement of kerosine from its important position was accentuated by the development of the burning of liquid fuel in furnaces and boilers, especially for marine purposes, and by the extended use of electric lighting, so that the once dominant product was displaced to a position of quite secondary importance.

It is hardly possible that such a violent change of centre of gravity can again be experienced, because the applications of other petroleum products are so rapidly extending in so many directions that no single product can ever again occupy the dominating position which gasoline has occupied during the last two decades. As examples may be mentioned the extension of the uses of asphalt for road making purposes and for other industrial purposes; of lubricating and other oils resultant from the development of the internal-combustion engine and of the electrical industries, as well as of machinery in general; and of gas oil or light distillate fuels for the ever-increasing number of compression-ignition engines. The question of the future centre of gravity of the industry becomes, therefore, rather complicated. However, as long as the bulk of the petroleum produced is used in some form or other as fuel, the development of the various types of internal-combustion engine must be the factor of prime importance.

The internal-combustion engine is developing along two definite lines, that of the spark-ignition engine and that of the compression-ignition engine, two types which demand two entirely different types of fuel. At first sight there would seem little overlap in the matter of supplies. This is, however, not the case as fuels for both types of engines are derived from the same source, namely, crude petroleum, and the supply of one type of fuel is definitely affected by the supply of or demand for the other type, quite apart from considerations of supply and demand for other petroleum products used as fuels. An increase in the demand for one product naturally results in an effort on the part of the manufacturers to increase the yield of that product from the crude oil. The splitting up of the crude oil is primarily effected by distillation, and the products are defined to some extent by their boiling ranges. As a certain amount of variation or flexibility in properties is permitted in the practical use of internal-combustion engine fuels, the crude oil refiner can vary to some extent the relative yields of the two types of fuel from the crude. Thus the yield of kerosine can to some extent be increased or decreased at the expense of gasoline on the one side, distillate fuel on the other. Moreover, some considerable further flexibility in this process is possible owing to the modern developments of the cracking process, which enables the refiner to convert heavy oil, to a large extent, into light gasoline. This process is, however, a complicated one, and the extent to which it can be applied depends on the relative prices obtainable for the crude cracking material and the resulting cracked products. Further complications arise from the fact that the distillate liquid fuels or gas oils are not entirely primary products of distillation but are to some extent secondary products resulting from the manufacture of other products, the demand for which may fluctuate quite independently of that for fuels. Distillate fuels such as gas oil result as by-products in the manufacture of lubricating oil and asphalt and also from the operation of the cracking process. It is obvious, therefore, that unless some unforeseen and totally unexpected development, such as a complete elimination of the spark-ignition type of engine by the compression-ignition type, takes place, the centre of gravity of the petroleum industry can never again be dominated by one product as was the case in the early days.

At the present time the developments which are taking place in the automobile industry, in the use of compression-ignition engines on land and sea, and in the uses of lubricating oil and of asphalt, are not taking place at equal rates, nor do their relative rates of development at present depend exclusively on the relative proportion in which the petroleum industry can supply the various

components required. But the rates of development of these industries must eventually depend mainly on the supply and price of suitable oil fuels, taking into consideration, of course, the efficiencies with which the various oils can be used.

The object of this paper is to consider the questions of fuel supply in relation to engine development, the directions in which changes in demand and supply may take place, and the ways in which they may be met, and to endeavour to suggest the direction in which the approach to equilibrium lies, in order that a closer co-operation between engine manufacturers and fuel suppliers, resulting in a better mutual understanding of the position and each other's problems, may prevent the occurrence of violent fluctuations in development and demand with their consequent ill effects on industry in general.

To approach the discussion of this subject one must study the developments which have taken place during the last few years and those which are taking place at the present time, and try to look ahead and forecast the directions in which such developments will proceed in the near future. The main points therefore which must be studied are :—

(*a*) The possibilities of future production of petroleum supplies. The possibilities of supplies of alternative fuels other than petroleum, and the qualities of such fuels.

(*b*) The proportions in which the various products result when the crude is worked up.

(*c*) The increasing demand for gasoline and distillate fuels for compression ignition engines, and the way in which they have been met.

(*d*) The direction in which the relative developments of internal combustion engines will turn the future demand for petroleum fuels.

(*e*) The effect of demand of other fuel users and of the demand for other products or purposes on the supplies and qualities of the heavier fuels.

(*f*) The extent to which the petroleum industry can adapt itself to varying demand for such fuels.

(*g*) The line of development which such considerations indicate the manufacturers of Diesel engines should follow.

(*a*) The question of future supplies of crude petroleum can be answered definitely in relation to the time factor. It is certain that petroleum in common with other natural products is being used up far faster than it is being made by natural processes, so that exhaustion is a question of time, but it is equally certain that the supplies available are sufficient for so many years to come, even if the present rate of increase of consumption is maintained, that no anxiety on this score need be at present entertained.

Table 1 shows the world production of crude oil for the last ten years :—

TABLE 1.

Year.	Tons.	%increase.
1919	77,857,100	—
1920	99,027,990	27·2
1921	109,295,000	40·3
1922	122,673,500	57·5
1923	145,557,100	86·9
1924	144,734,100	85·9
1925	152,509,400	95·8
1926	156,658,400	101·2
1927	178,878,000	129·6
1928	189,500,000	143·3

These figures, which look so large when expressed in tons, dwindle to insignificance if expressed in terms of a unit, such as a cubic mile, in terms of which rock might be measured. The total world's production to date falls far short of one cubic mile. The estimation of future oil reserves with the data at present available is a difficult if not an impossible problem. For example, California alone has produced more oil than the total which was estimated as the available supply thirteen years ago, and California is far from being exhausted. Apart from the development of new areas, deeper drilling in existing fields is opening up new and prolific sources of supply and bringing to life again fields which were considered as moribund or dead. Moreover, present methods of extraction leave the bulk of the oil below. It is no exaggeration to say that for every ton extracted at least three tons are left below. The extraction of this great reserve is a problem which faces the industry to-day, but which is certainly capable of solution. The author refrains from making any rash guesses as to future supplies but feels confident that there is ample for all requirements for many years to come. Assuming, however, the exhaustion of petroleum supplies there are available enormous quantities of shale which, on distillation but at a great cost, yield oils closely resembling petroleum in character. The potential supplies of such oils are so great as to take us right out of our field of view. It is not the purpose of this paper, however, to discuss the situation so far ahead, but to consider only the developments of the next few decades, when ample crude oil supplies will still be available. This brings us to the second point.

(*b*) Crude petroleum is the basis for the manufacture of many types of fuel and other products ; gasoline, kerosine, distillate fuel oils and residual fuels on the one hand, lubricating oils, paraffin wax and asphalt on the other. Crude oils from various fields show great divergencies in character, both in respect of type, yield and quality of the various products. Most crude oils yield some gasoline, all some distillate fuel by primary distillation, all can be made to yield gasoline by the special cracking processes. (This will, however,

for the moment be ignored as it is not a primary process.) Lubricating oils can be extracted from or left in the residual fuel as required, so can paraffin wax : thick residual fuel can be worked up into asphalt and thin distillate fuels ; kerosine fractions can be partly diverted into distillate fuel or vice versa, and so forth, according to demand. But there are obviously limitations to such flexibility. Such variations are illustrated by the data given in Table 2 :—

TABLE 2.

Principal products made from average U.S.A. crude.

Year.	Gasoline.	Kerosine.	Fuel Oils.	Lubricants.
1899 ..	12·9% ..	57·6% ..	14·0% ..	9·1%
1904 ..	10·3% ..	48·3% ..	12·8% ..	11·6%
1909 ..	10·7% ..	33·0% ..	33·6% ..	10·7%
1914 ..	18·2% ..	24·1% ..	46·5% ..	6·6%
1919 ..	25·2% ..	15·4% ..	50·2% ..	5·6%

A critical examination of the complete significance of these figures is beyond the scope of this paper. The relative changes in the figures for gasoline and kerosine prior to 1919 sufficiently illustrate our point.

(*c*) The increasing demands for fuels for spark-ignition and compression-ignition engines, the changes which are taking place in this field and the way in which they have been met by the petroleum industry up to the present are illustrated by further data. In Table 3, figures illustrating the growth of the automobile industry are given :—

TABLE 3.

World Motor Vehicle Registration.

Year.	United States. No.	Increase.	Rest of World. No.	Increase.	Total World. No.	Increase.
1919 ..	7,565,446	— ..	1,286,948	— ..	8,852,394	—
1922 ..	12,239,853	62% ..	2,379,091	85% ..	14,618,944	65%
1925 ..	19,954,347	165% ..	4,519,282	251% ..	24,473,629	177%
1928 ..	24,493,124	224% ..	7,285,079	466% ..	31,778,203	259%

TABLE 4.

Year.	Total production of gasoline U.S.A. in barrels.	Yield on crude oil %
1905 ..	7,900,000 ..	5·91
1914 ..	34,900,000 ..	13·14
1917 ..	64,290,000 ..	21·15
1919 ..	94,235,000 ..	25·2
1920 ..	116,704,000 ..	26·1
1921 ..	122,704,000 ..	27·1
1922 ..	147,672,000 ..	28·8
1923 ..	179,903,000 ..	30·0
1924 ..	213,326,000 ..	31·2
1925 ..	259,601,000 ..	32·4
1926 ..	299,734,000 ..	34·9
1927 ..	330,435,000 ..	36·0
1928 ..	377,183,000 ..	37·5

The way in which the petroleum industry has responded to this rapidly increasing demand is illustrated by the figures given in Table 4, taken from United States statistics. (As the United States produces nearly 70 per cent. of the world's total supply of gasoline these figures will suit our purpose sufficiently well).

From these figures it will be seen that (1) in the early days when kerosine was still the dominant product the increased demand for gasoline was met by increasing the yield obtained from the crude oil by simple distillation, at the expense of the kerosine, the gasoline changing in quality accordingly (2) that the yield of gasoline apparently still goes on increasing. There is a point here, however, that the figures given in this table do not bring out and that is that about 25 per cent. is the maximum yield of usable gasoline which is obtainable by ordinary distillation methods. Up to about 1920 therefore the gasoline produced was almost entirely of the straight run (or simply distilled) type and the demands of the automobile industry were thus adequately met. About that time the demands of the automobile industry for gasoline began to exceed the supplies available from the crude produced at that time. These demands could only be met by (1) increasing crude production in excess of the demands for the other products, or by (2) increasing the yield of gasoline at the expense of the other products. The second of these alternatives was adopted and the means of effecting it was found in the newly developed cracking process. By the aid of this process the yield of gasoline from the crude was increased considerably at the expense of another component of the crude, which was in excess of requirements, that component being the distillate fuel. The growth of this new process is illustrated by the figures given in Table 5 :—

TABLE 5.

Production of Gasoline by Cracking.

Year.	Barrels.
1918	8,500,000
1920	15,000,000
1922	30,000,000
1924	40,000,000
1926	93,736,000
1928	122,381,000

About the same time the increasing demand for gasoline initiated another industry, viz., the extraction of light or volatile gasoline from the vast quantities of natural gas which many oilfields produce. These light fractions are valuable because of their volatility and good antiknock value. The annual production of this so-called natural gasoline now is estimated at about 47,000,000 barrels. The effect

of these two new developments on the gasoline position is shown by the data of Table 6.

TABLE 6.

Estimated % of Total Gasoline Made in U.S.A. by the Three Methods.

Year.	Straight Run. %	Cracked. %	Natural. %
1918	89	10	1
1924	74	19	7
1926	60	31	9
1928	58	32	10

In the future these relative proportions will show still further changes. The percentage of straight run gasoline, of the present type, to be extracted from the crude oil cannot increase, the supply of this commodity will only increase pro rata with crude oil production. The percentage of natural gasoline will increase to some extent as in many fields the gas is not yet fully worked up for gasoline. The main increase is, however, to be looked for in the cracked gasoline, as this is obtainable from the heavier fuels. This increased yield of gasoline is thus being effected mainly at the cost of the component, a distillate fuel of the gas oil type, which is the product most in favour for compression-ignition engines, so that the supply of light spark-ignition engine fuel is being increased at the expense of the compression-ignition engine fuel. What will this mean in the future ?

Of recent years the compression-ignition engine has been much improved and is being developed in directions which should make it much more available for general use, and eventually for transport purposes. A discussion of the relative advantages of these two types of engines is beyond the scope of this paper. Suffice it to say that the lower consumption and particularly the present lower price of the fuels used by the compression-ignition engine are its two most attractive features. The use of these engines in their present state of development is increasing by leaps and bounds. The yearly sales in the United States are given in Table 7 :—

TABLE 7.

Year.	Yearly sales in h.p.	% increase.
1919	70,000	—
1922	85,000	21·4
1923	140,000	100·0
1924	200,000	186
1925	330,000	372
1926	285,000	307
1927	375,000	437
1928	420,000	500

This h.p. is distributed approximately as follows :—

	%
Central electric stations	18
Oil pipe-line pumping stations	20
Marine	26
Refrigerating plant	5
Others..	31
	100%

The Diesel engined ship is rapidly developing. In 1914 the total tonnage of such vessels was only 234,000 but in 1922 it had increased to 1,542,000. At present it has reached 6,628,102. About 40 per cent. of the tonnage now under construction will be driven by Diesel engines.

Although many Diesel engine manufacturers claim that their engines will operate successfully on residual fuels, general practice is to use either distillate oils or very light residuals. The reason for this is certainly not any real inability on the part of Diesel engines to burn residual fuels but largely to the difficulties of storing and heating thick residuals and of clearing them from foreign insoluble matter. In this connection one may recall the fact that Dr. Diesel's original idea was that of an engine to burn powdered coal and note that efforts in this direction are still being made, and that some measure of success has actually been attained.

Figures for the production of distillate and residual fuels in the U.S.A. since 1919 are given in Table 8 :—

TABLE 8.

Year.	Tons.	Percentage on crude oil.
1919 ..	30,267,000 ..	50·2
1921 ..	38,349,000 ..	51·9
1923 ..	47,913,500 ..	49·5
1925 ..	60,832,000 ..	49·3
1927 ..	65,511,000 ..	47·4
1928 ..	70,956,000 ..	46·7

There is obviously no tendency for the yield of fuel oils from the crude to increase. It is, unfortunately, difficult to obtain accurate statistics showing the relative proportions in which distillate fuels (gas oils) and residual fuels are produced. There is no source from which accurate information as to the quantity of distillate fuel used for cracking can be obtained, so the increased demand from this source must be judged by the increase in production of gasoline made in this way, vide Tables 5 and 6.

The increasing demands for gasoline and for compression-ignition engine fuels have thus so far been met by the petroleum industry (*a*) for gasoline, by increasing the production of crude oil

and by increasing the yield of gasoline by means of the cracking and natural gas industries ; (*b*) in the case of compression-ignition fuels by no special effort, as the increase in the production of crude oil has so far been able to supply the demand. The vital question for Diesel engine manufacturers is, however, to what extent or for how long the industry will be able to meet the rapidly increasing demands for distillate fuel oils before the law of supply and demand brings about the inevitable increase in price. In any attempt to answer these questions further factors must be discussed, viz., the trend of future development in Diesel engines, the demand of users of distillate fuels for other purposes and the possibility of increased yield of distillate fuels as by-products when making other products.

(*d*) Of the future demands for petroleum internal combustion engine fuels of both types it may be safely said that the present rate of increase will be maintained and even exceeded. The demand for compression-ignition fuels is as yet only in its infancy. The trend of future development of Diesel engines is certainly in the direction of (1) increased production of the existing type, and of (2) the development of a high speed type of engine. This latter is probably the more important, as the reduced weight per h.p. of such engines opens out their possibilities for use for transport purposes, for tractors and trucks, for railway locomotives, for ships and barges, possibly for automobiles and even for aeroplanes or airships. It is impossible to forecast the extent of such developments, but there is no doubt about the result. A very considerable increase in the demand for distillate fuels will arise. The increasing demand for gasoline will be met by increasing the production of crude, by increasing the yield of gasoline by improved cracking methods, and by altering the design of spark-ignition motors so as to run on less volatile fuels. Such demand could be further met by alternative fuels such as alcohols. A large increased demand for Diesel fuels of the distillate type could also be met by increasing the yield of such fuels by including kerosine fractions, or by distilling down to thicker residual fuels, to both of which processes there are objections. The controlling factor is really price, and, as there are other competitors for these distillate fuels, an important question is the effect of this competition.

(*e*) The problem is complicated by the fact that there are not only other important and rapidly growing demands on the supplies of the distillate fuels but also that on the other hand there is a growing industry which affects the production of such distillate fuels as a by-product. There is a steady demand for gas oils for gas enriching purposes, but this demand is not likely to show any

rapid increase. But the developments which are rapidly taking place in the use of automatic central oil heating plants, not only for factory and office purposes, but also for domestic purposes, are creating a rapidly increasing demand for these distillate fuels. The Oil Heating Institute estimates that in 1929 there were over 600,000 domestic oil burners in houses in the U.S.A. and that in the spring of 1930 this number would be increased to 800,000. The growth of the demand is shown by the figures in Table 9 :—

TABLE 9.

	Number of domestic burners operating.	Tons of oil used.
January 1921	12,500	—
1923	58,800	—
1925	181,800	402,600
1927	221,500	1,261,300
1929	422,700	1,765,100

The increase which has taken place during the last five years is an interesting example of the economic trend of the times. The potential market for fuel oils in this direction can well be imagined. Apart from the demand for oil for domestic heating there is that for commercial oil heating to be considered. The Oil Heating Institute gives the estimates shown in Table 10 for distillate oil fuel used for this purpose in the U.S.A.

TABLE 10.

Winter.	No. of installations.	Tons of oil used.
1925/1926	24,000	1,710,000
1926/1927	27,800	1,980,000
1927/1928	30,300	2,164,000
1928/1929	33,550	2,393,000

The possibilities of expansion in these directions are certainly great. Reference has already been made to the demand caused by the cracking process for making gasoline from distillate fuels. On the other side of the picture must be noticed the growing asphalt industry. Asphalt is the solid or semi-solid sticky residue resulting from the further distillation of certain residual fuels. Asphalt, however, is a product which only a limited number of crudes can produce. Certain types of crude yield no asphalt, others yield it in such small proportion that its extraction is not an economic process. When such suitable residual fuels are distilled down to asphalt the distillate oils given off may certainly be used as compression-ignition engine fuels, so that an augmentation of the supply of these would apparently result from an increase in asphalt production. As the yield of asphalt depends on the nature of the residual fuel as basic material and as asphalt can be and is manufactured in various

grades, it is impossible to say precisely that a definite quantity of asphalt made results in the simultaneous production of a definite quantity of distillate fuel. A very rough figure only can be stated. For every ton of asphalt made, about one-third of a ton of distillate fuel might result. Asphalt is supplied partly from natural sources (*e.g.*, Trinidad Lake), partly from petroleum distillation. The proportion supplied from petroleum is steadily increasing. The use of asphalt for road-making and for various industrial purposes is steadily increasing. Thus in 1918 the production in the U.S.A. was 1,202,420 tons, while in 1929 it had reached 3,302,400 tons. It is practically impossible to forecast the extent to which the asphalt industry may develop. Out of a total of 300,000 miles of State and Federal highways in the United States only 65,000 or so are yet paved with asphalt, concrete or brick. The extent to which asphalt will be used for new construction in relation to tar, concrete and possibly rubber is a problem insoluble by the aid of existing data. On one point, however, there is certainty: increase in the mileage of good roads will bring about increased consumption of engine fuel whether it be spark-ignition or compression-ignition fuel.

Thus, the distillate fuels so much in favour for Diesel engine use are also in great and increasing demand: (*a*) for the manufacture of motor spirits by the cracking process; (*b*) for use for domestic heating purposes. It is indeed true that both these demands are increasing at great rates. The increasing asphalt industry is doing something to augment the supplies of distillate fuels. But there is yet another demand which merits much consideration, namely, that which will result from the impending development of the high speed Diesel engine. The advent of this type will enormously widen the field of application of the Diesel engine. The demand so brought about will be for fuels of the distillate type, as the high speed Diesel engine will certainly, in its initial stages at any rate, be less capable of running on residual fuels than the existing types of relatively slow speed engines.

(*f*) What can the petroleum industry do to adapt itself to such changing conditions? The main primary products made from crude petroleum are:—

1. Gasoline.
2. Kerosine.
3. Gas oils or distillate fuels.
4. Residual oils.

The maximum yield of gasoline made as a primary product suitable for modern auto-engines has already been reached. The yield of primary (or straight-run) gasoline could be increased at

the expense of the kerosine fraction by increasing its boiling point range. Progress in this direction is, however, barred as increase in boiling point means decrease in anti-knock value, and the demand is more and more clamorous for gasoline of high anti-knock value. The yield of gasoline of the requisite volatility or boiling point range and anti-knock value can, however, be met by cracking heavier fuels. Although cracking of residual fuels can be and is being effected, the process is more easily applied to the distillate fuels, which will thus be in ever-increasing demand for this purpose. The yield of kerosine is small, the more so as those crude oils now most abundant which yield gasoline of good anti-knock value give kerosine of poor illuminating value. In any event the demand for kerosine is on the wane, so that much of this product which under other conditions would be made finds its way into distillate fuels or gas oils.

The yield of distillate fuel which is a product intermediate between gasoline, on the one hand, and residual fuel on the other is thus limited.

The limit to the production of gasoline would thus be reached when the whole of the distillate and residual fuels were used as cracking base products. The supply of distillate fuels available is thus being eaten into by the demand for motor spirit and for domestic fuels. It is being augmented by the manufacture of asphalt residual fuels. The maximum yield of distillate fuel would be attained only when none of it was used for cracking and when all residual fuel was distilled down to asphalt. The petroleum industry is flexible, but there are limits to this flexibility.

The maximum yield of straight-run motor spirit, say 25 per cent. of the crude, has been reached. The maximum yield by full use of the cracking process might be raised to, say, 65 per cent. The maximum yield of distillate fuels, if none were used for cracking and all crude distilled as far as possible, might be also as high as 65 per cent. Neither of these conditions is obviously likely to be realised. There is, however, a development, at present in its infancy, which may later on give the petroleum industry a much greater flexibility and which may possibly render available supplies of oil from coal. Attempts are being made to manufacture commercially light oils from heavy oils by means of hydrogenation. Information as to progress in this direction is, however, not yet generally available. Given cheap supplies of hydrogen such as may well be obtained by the cracking of natural gas, the supply of gasoline might well, by this process, be considerably augmented. For basic material for such hydrogenation the distillate fuel oils would certainly be in great demand.

What do these considerations indicate ? What are the directions in which development may be expected ? There seems no reason for expecting any retardation in the expansion of the spark-ignition engine. However far the Diesel engine develops, it may be confidently expected that the gasoline engine will hold its own even with a more expensive fuel. That the Diesel engine is rapidly approaching a state of development which will bring about a rapid extension of its uses is beyond dispute. The resulting competition for distillate fuels will certainly result in a rise in price of such fuels in comparison with gasoline. One of the main arguments for the Diesel engine is at present the lower price of the fuel. An increase in the relative price of this fuel must result in a retarding effect on the development of the Diesel engine. In the case of marine Diesels an increase in the price of fuels might well in many cases give the advantage to the steam turbine. Some state of equilibrium must eventually be reached, but the point at which this will be set up is beyond the power of the author to predict.

One solution, however, does present itself, or rather one direction for future development is clearly indicated. There is a relative abundance of residual fuel. The spark-ignition engine cannot use this, but the engine of the Diesel type can. The only competitors for residual fuel are the steam raisers and heat generators, and these have always coal available. The day may come when the dream of Dr. Diesel will be realised and powdered coal will be the standard Diesel fuel. Meanwhile, the intermediate step seems to be the evolution of a type of engine which will burn successfully the residual petroleum fuels for which the competition can never become fierce as long as there is abundance of coal and which may certainly be expected for long years to come to be the cheapest petroleum product. Many, if not most, Diesel engine makers claim that their engines can use such fuels, but the users of the engines seem to think otherwise. The development of the Diesel engine to substantiate the makers claims as to its capacity for running on residual fuels appears to the author to be the line most clearly indicated.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

TWELFTH ANNUAL DINNER.

THE TWELFTH ANNUAL DINNER of the Institution of Petroleum Technologists was held at the Connaught Rooms, Great Queen Street, London, on Friday, October 10th, 1930, the Chair being taken by the President (Dr. A. E. Dunstan), who was supported by Mr. Alfred C. Adams (Past-President), Professor J. S. S. Brame, C.B.E. (Past-President), Mr. Ashley Carter (Member of Council), Mr. A. E. Chambers (Vice-President), Mr. G. H. Coxon (Member of Council), Mr. C Dalley (Member of Council), Mr. T. Dewhurst (Member of Council), Mr. Arthur W. Eastlake (Vice-President and Honorary Secretary), Mr. B. J. Ellis (Member of Council), Mr. J. S. Jackson (Member of Council), Mr. E. Lawson Lomax (Member of Council), Mr. J. McConnell Sanders (Member of Council), Mr. George Sell (Assistant Editor), Commander R. E. Stokes-Rees, R.N. (Secretary), Mr. William Sutton (Member of Council), Dr. F. B. Thole (Member of Council) and Dr. A. Wade (Member of Council).

Among those present were also: Lieut.-Col. S. J. M. Auld, O.B.E., M.C., Mr. J. Courtenay Clarke, C.B.E., Mr. H. W. Cole, C.B.E. (Director, Petroleum Department), Major R. C. Cole, M.B.E., T.D., Major Sir T. H. Crozier, Kt. (H.M. Inspector of Explosives), Mr. Homer S. Fox (American Commercial Attaché), Mr. W. W. Grierson (President, Institution of Civil Engineers), Mr. A. C. Hearn (Anglo-Persian Oil Company), Professor J. W. Hinchley, Dr. C. H. Lander, C.B.E. (Fuel Research Board), Sir William J. Larke, K.B.E. (Director, National Federation of Iron and Steel Manufacturers), Professor J. G. Lawn, C.B.E. (President, Institution of Mining and Metallurgy), Dr. H. Levinstein, Dr. E. R. Lilley, Sir Frederic Nathan, K.B.E. (Department of Scientific and Industrial Research), Professor Partington, Mr. George Patchin (Sir John Cass Technical Institute), Sir Joseph Petavel, K.B.E. (Director, National Physical Laboratory), Eng.-Rear-Admiral G. Preece, R.N., Sir Alexander Prince, K.B.E., Mr. J. Arthur Reavell (President, Institution of Chemical Engineers), Colonel the Master of Semphill, A.F.C., and Prof. J. F. Thorpe, C.B.E., F.R.S. (President, Chemical Society).

"The R101."

The President: Gentlemen, I would ask you to stand in silence for a few moments to pay honour and respect to our great dead of "R101." (The assembly stood in silence for a short time.)

"The King."

The Toast of "The King," proposed by the President, was loyally honoured.

The President: Gentlemen, I have one or two announcements to make. As you know, we have several important branches that on such occasions as this invariably express to their parent Institution the very best of good wishes. I am quite certain, Gentlemen, that you would like us to return to all our branches —Persia, Trinidad, Rumania and South Wales—our very best appreciation of their good wishes.

It would have been our pleasure on this occasion to present the Students' Medal and Prizes, but unfortunately the winners are away in Rumania on a travel trip. The Students' Medal and Prize was awarded to Mr. L. C. Stevens for his paper on "A Method of Increasing the Yield of Oil Sands, with Special Reference to Repressuring." A special prize has also been awarded to Mr. P. N. D. Porter for his paper on "Field Applications of Electricity," and Mr. A. P. Chamberlain has been honourably mentioned for his paper on "Mechanical Design in Relation to Detonation." Those three papers all came from students at the University of Birmingham.

"Applied Science and the Technical Societies."

Sir William J. Larke, K.B.E. (Director of the National Federation of Iron and Steel Manufacturers), in proposing the toast, said: I would remind you that applied science is not only the foundation of modern industry, but it is really the whole basis of our modern life; never was the application of science more important in the history of this country, or indeed of the world, than to-day, when the application of science is required to replenish an impoverished world. Those countries will win the race for prosperity, which are first in the discoveries of science, and have the courage and the enterprise to apply those discoveries to their industries. The application of scientific research to our industries (which has received, as I think, a very valuable impetus through the Government Department of Scientific and Industrial Research) ought to be stimulated by industrial depression instead of, as I fear is far too often the case, retarded. After all, industrial research properly applied may well be the lifebuoy which will carry an industry from the trough of depression to the crest of

prosperity. I feel that it is to the scientist that we must look largely for our economic recovery. But if we are to look to him for assistance in our economic recovery, may I ask him, as a humble technician, to try to express his discoveries in a way which is comprehended by the people? Far too often the scientist criticises the technician and the industrialist for faults which are really his own, since he does not make his discoveries comprehensible, and therefore he loses the co-operation of those who alone can convert his discoveries to the benefit of mankind.

The application of science has had a profound influence in shaping the modern world. I have had the good fortune to be associated with two industries, the development of which depended upon the application of science: one at its birth and the other long after it was established as an industry. I will take the last first. The Iron and Steel Industry may be said to have dated from what is historically called the Iron Age. In the early history of man, at least 3,000 years before the Christian era, iron implements had been found accurately dated, and that industry was developed empirically to meet the needs of mankind, but it was not until the eighteenth century that science was applied to the Iron and Steel Industry. In 1750, when Darby first commenced to smelt iron with coal, later when Court invented the rolling mill, and later still when the inventions of Bessemer, Siemens, Thomas, Gilchrist and others produced iron, and subsequently steel, in such quantities that they could form the basis of modern industry; then, and not until then, the industrial revolution and its subsequent developments were made possible, and indeed they laid the foundation for the industry with which your Institution is particularly associated. I wonder who would be so bold as to say that the application of science to your own or to some other industry may not in the future hold as profound an influence in adding to the comfort and to the ultimate history of mankind as profoundly as those applications have influenced the Iron and Steel Industry.

The second industry in which I grew up was the Electrical Industry, which was born in the laboratory of the Royal Institution on August 29th, 1831, when Faraday discovered the phenomenon of electro-magnetic induction. It was my privilege in the late years of the nineteenth century, and in the early years of this century, to be associated in a humble capacity with the development of the application of electrical power to industry. Never, in what I think may fairly be called a rather more than average strenuous life, have I felt the thrill of enthusiasm and exaltation to a greater degree than during those years when every problem presented to us was without precedent, and when we succeeded in technically overcoming difficulties which permitted the application of that

phenomenon to the use and service of mankind. There is no satisfaction which can be given to mankind equal to that of the scientist and the technician who is the first to solve any problem in the application of natural resources in that way.

I would emphasise the importance that science and scientists have in our modern world in assisting the world, and particularly this old country of ours, towards economic recovery, the restoration of prosperity to our industries, and employment to our people.

Science is a hard task-mistress. She exacts the highest and the best from us, but there have never been wanting those who have been willing to sacrifice material comforts, health, and even life itself, in her service. If to-day we mourn a sacrifice on the altar of science almost unparalleled in magnitude we do so with a thrill of pride, and with knowledge that what has happened will only be a stimulus to further effort in the same field of endeavour. To the true scientist failure but creates an additional opportunity in that it has brought him additional knowledge which enables him to progress still farther from one discovery to another. He is blessed indeed in that he is always living with an ever-expanding horizon.

There is laid upon you, gentlemen, and upon those others who represent the technical societies here, a great responsibility at the present time, and I know that you will respond to it.

It is my privilege to couple this toast with the name of one who has distinguished himself by his personal courage, initiative and originality in not only developing and extending the science of aeronautics but its practical application to aviation. I am referring to our distinguished guest, the Master of Sempill. (Applause.) I can conceive of no one more worthy to assume the great responsibility of speaking in the name of applied science. With these few words I commend to you this toast with that reverence and with that enthusiasm which is commensurate with its importance. (Applause.)

The toast, "Applied Science and the Technical Societies," was then enthusiastically honoured.

Colonel The Master of Sempill, A.F.C., in responding to the toast of "Applied Science and the Technical Societies," said :—

Mr. President, Sir William Larke and Gentlemen, I rise with great trepidation, and with considerable diffidence, to attempt to reply to the toast which you have just honoured so enthusiastically, and which was so admirably proposed by the Director of the National Federation of Iron and Steel Manufacturers. He speaks with authority as a leader of one of the greatest, if not perhaps the greatest, industry in this country, and all that he says must commend itself very seriously to our attention.

I feel that in inviting me to reply to this toast your Institution is paying a compliment to aeronautics, because the science of aeronautics and the Institution of Petroleum Technologists are already closely bound together by many ties, and I hope that they will be bound still closer in the near future. Although the science of aeronautics is very young it might interest you to know that the Royal Aeronautical Society, now embarking on its sixty-fifth year, has the privilege of being immeasurably the oldest aeronautical society in the world.

The importance of the application of science needs no emphasis to an audience such as this. I suggest, however, that we need to use, to an even greater extent than we do now, all our efforts—individually and through the various societies and institutions to which we belong—to try to bring about a fuller appreciation of the immense importance and advantages of the application of science to the affairs of the nation. In my opinion there is much to be said with regard to the possibility of strengthening the position of the various scientific and technical societies in order that they may be able to do their work more efficiently, and that their voices can be heard to a much greater extent than is possible to-day. I refer to that movement which I think originally owed its inception to one who was closely bound up with your Institution, Sir John Cadman, and which was admirably carried on by Professor Thorpe, Sir Arnold Wilson, and one or two others. They have now, as you know, brought about a state of affairs whereby there is a sum exceeding £100,000 available, and more promised, for the acquisition of a central building where a number of scientific and technical societies will come together and thereby greatly increase their value to the nation at large. (Applause.) Speaking from the point of view of my own Society, I can say with certainty that we cordially welcome the scheme and hope to be able to participate. There is to be a dinner on November 13th next at which His Royal Highness the Prince of Wales will be present, when the whole of this scheme will be put before the general public. If I might be so bold as to say so, I hope and sincerely believe that it is a scheme which has already recommended itself to the Institution of Petroleum Technologists.

It appears to me that aviation provides one of the finest examples of the application of science. Consider, for instance, the wonderful increase in performance and in duration which has occurred in aviation during the last 25 years. It is only just over 25 years ago that the first power-driven controlled flight was made by man. Since then a distance, something like 850 feet, has increased to 4900 miles in a straight line. (Applause.) The duration, of 69 seconds, has now increased to 67 hours in an heavier-than-air

machine. The height, which was then negligible (so much so that observers had to lie on the ground to see whether they could observe daylight between the top of the grass and the wheels) has now exceeded 42,000 feet, and it is liable next year to be considerably increased. The speed, which I suppose one might hopefully suggest in those days was certainly not much more than 30 miles an hour, has now officially equalled 357 miles per hour. I do not suggest that during the next period of 25 years we shall see equal advances in this particular direction, because there are natural laws which will prevent it, but if development to the same extent is carried on, or even increased as one hopes it will be, we shall see greater progress in other directions. Putting on one side the military branches of aviation, the importance of which we realise, and taking only the civil and the commercial sides, the countries of the world are subsidising those services to the extent of at least five million pounds per annum, from which you will see the value they place upon more rapid communications for mails and passengers. When you think, too, that in the year which is now drawing to a close nearly 200 million miles will have been flown on the regular air lines you will see that aviation is indeed beginning to become a power in the world. (Applause.) Last year Great Britain alone was carrying 25 per cent. of the passenger total of the world, which was not inconsiderable. (Applause.) In one particular direction the aeronautical community looks to your Institution for help, as it has looked not in vain in the past. I remember clearly the splendid and very helpful lecture which was delivered to us not long ago by your President, Dr. Dunstan, in regard to the numerous problems that surround the production of suitable fuel for use in ultra high compression aircraft engines. The engine which was successful in winning the Schneider Trophy contest took under 12 months to design, manufacture and test. This was in itself a record, materially aided by the work of your Institution. The engine developed over one horse power for under one pound of weight, and enabled us not only to win the Schneider Trophy contest, but to secure and to hold to-day the world speed record in the air. (Applause.) I hope that those of you who can will do all that is possible to facilitate the carrying on of contests of an international character like the Schneider Trophy contest, because without an international impetus such as that it is fair to assume that the development in speed and performance would not have been so great.

Turning back to the application of science to aeronautics, we are always looking for new and improved materials for the construction of better aircraft, which will carry a greater load per pound of structure weight. Improvements in this direction will

help us gradually to approach the desired goal, namely, that civil aviation should fly by itself without subsidy. At the present moment great developments are taking place in the art of flying without an engine, utilising the power latent in the atmosphere. When one considers that a flight of over 100 miles in a straight line at a speed of about 25 miles per hour has been made by a motorless machine one can realise some of the possibilities.

Might I, in conclusion, say one word with reference to the disaster to R101, which was referred to by your President before the commencement of this dinner? There we had one of the most remarkable engineering structures of the century. All those people who set out in her so hopefully last Saturday thoroughly believed in the future of air transport, and also of the lighter-than-air craft. Sad as the event is which has happened, it in no way whatever shakes my personal belief in the great value of such craft, particularly for the British Empire, where we have long overseas distances to cover. I do beg you, gentlemen, to use your influence to prevent your people jumping to hasty conclusions, as so many people are doing, but to urge them to await the findings of the official court of inquiry. There is really nothing to be said as to the cause of the accident. It is being fully investigated, and the different claims put forward by various press journals "having particular knowledge" as to why this or that occurred should really not be paid any attention to at the present juncture.

The loss of life is a terrible national calamity, and a great calamity from which the aeronautical community will take some considerable period to recover. The best tribute we can pay to those who have gone is to carry on more energetically than ever. The late Sir Sefton Brancker, a close personal friend of mine, always said to me that when he died he would like to die in the air, doing his job, and that he wanted all those who were left behind to carry on with redoubled energies in furthering the cause of aviation, in which he believed so intensely and the importance of which, to the future welfare of the British Empire, could not be over-estimated.

Mr. President and Gentlemen, I thank you for listening to me so patiently, and for the enthusiastic manner in which you received the toast which was originally proposed. (Applause.)

"The Institution of Petroleum Technologists."

Dr. H. Levinstein, in proposing the toast of, "The Institution of Petroleum Technologists," said :—

Mr. President and Gentlemen, my task to-night is to propose the toast of "The Institution of Petroleum Technologists." The Master of Sempill has relieved me, not of the distinction, but of a considerable part of the burden of proposing this toast at all

adequately. The Master of Sempill is one of those people with whom we who are engaged in industry are glad to be associated; he is one of those people who live dangerously, and who use science for the purpose of overcoming the danger to which they would otherwise succumb. He has told us, directly and indirectly, of the great services which the Institution renders to those who are in this very fascinating and interesting profession. I have the greatest pleasure in coupling this toast with the name of your President, Dr. A. E. Dunstan, to whom I am personally extremely indebted for the support and assistance which he has given to me during the last two years, when I have presided over the Council of the Society of Chemical Industry. I would like to associate myself most warmly with what the Master of Sempill said with regard to the debt which we owe to Sir Arnold Wilson for the driving force which he has put behind the scheme for developing a common building for the whole of the technical societies. It is to his personality that we shall owe the success of this scheme, the success of which is imperative now that we have enlisted the support of the Prince of Wales in the movement.

One of the most remarkable features of your Institution is the great progress which you have made in a very short number of years. I suppose that that is largely due to the *esprit de corps* which you have. That, by itself, is a very fine thing, although to very many people it is a difficult thing. I am referring to the very loyal service which you have received from so many of your members. Thanks to the work of the Editor of your Journal, and of other members of your Institution, the Institution has flourished at an exceptionally rapid rate. You look after your students. The Journal is written in a language which is apparently understood by your South Wales members, and by your American members, your Persian members, your Trinidad members. That is a very remarkable achievement, and I put it down largely to the very fine *esprit de corps* which you have among those who serve you so well.

One of the things from which we are suffering more than anything else to-day is unemployment. It is a very curious thing that a great deal of the unemployment is due to the fact that everything is too cheap. People are starving because bread is too plentiful. People cannot buy their commodities because there are too many of them. It is a paradox that people should be starving because there is too much food, and, really, I do not now believe one single thing that any economist has ever said, or ever will say. I do not believe that there is anybody in the country who knows anything about currency, or economics. We are groping in the dark. I really believe that we might do worse than start by making certain things

dearer, and one of the things which I should like to see made dearer is oil. (Laughter.) I do not want you to make any more profit out of it. It would be a good thing for this country if we were to put a really big duty on oil. I think that oil, and oil transport, are too cheap. I think that the competition to which our coal-fields are subjected by the very cheap price of imported oils is an economic disadvantage to this country. It has this great disadvantage, that it is ruining the railways, and making mechanical transport too cheap. I am not sure that we should not be wise if we did what they have done in Italy, and put a big duty on oil in order to help the railways and to preserve the roads. I am perfectly certain in my own mind that this country cannot afford to spend the money on the roads which it is spending to-day. If one looks at the unemployment problem with some intelligence I am not sure that one can do any one thing which would be of more advantage in diminishing unemployment than to put a very big duty on oil. You could put a very substantial duty of 5d. or more per gallon on to oil, and thereby encourage directly the development of low temperature carbonisation and hydrogenation of coal in this country. I should like that done, although I have no interest in low temperature carbonisation. I have no doubt whatever that if we were to develop it to a profitable extent the oil people would take charge of it. I do think that as coal is our most important raw material it would not be an illogical but rather a sensible thing to keep in the country as much of the money which we now spend on oil as we can possibly use in the purchase of coal. There would be other advantages, including the advantage of sending rather less money to America than we do at present. That would make our cities rather less murky, and it would make our railway directors, of whom one of your distinguished past-presidents, Sir John Cadman, is now one, rather more cheerful, or rather less gloomy.

Before I sit down I would like to say, quite seriously, that we outside look forward to being more closely connected with your Institution.. We have the greatest admiration for the work which you are doing, and for the services which you are rendering to your own branch of technology so closely allied to our own, and which will undoubtedly in the next generation be very much closer allied, because the raw materials, the hydrocarbons derived from oil, will undoubtedly, in the next generation, be the foundation for organic chemical industries analogous to those which the last two or three generations have seen built up on the hydrocarbons obtained from coal.

Coming from Manchester, as I do, I should like to refer to the wonderful work which has been done by the cancer research people

there, in which work the petroleum industry is playing a distinguished part. I believe that your Institution is itself directly concerned in that cancer research programme which, according to the medical people, has really conquered one of the outposts of the fort. In doing that, you have rendered a service to humanity which is little known. That adds one more to the great functions which you perform in the world.

I have the greatest pleasure in proposing the toast of "The Institution of Petroleum Technologists," and coupling with it the name of your distinguished President, Dr. A. E. Dunstan.

The toast was enthusiastically honoured.

The President, Dr. A. E. Dunstan, in responding to the toast of "The Institution of Petroleum Technologists," said :—

Dr. Levinstein and Gentlemen, I have been asked by the Master of Sempill to express his regret at having to leave us so early this evening. He has to receive Dr. Eckener, of the Zeppelin Company, who is coming to town to-night on behalf of the German Government. I am sure that after having heard the Master of Sempill's most eleoquent speech we regret very much that he could not remain with us until the conclusion of the proceedings.

After Dr. Levinstein's exceedingly kind words about the Institution may I say how honoured I am to be here to-night, and to have at this table two presidents of the premier chemical societies of the world? I speak on this occasion as an ordinary and a very humble chemist. It is really to me a personal pleasure to welcome Professor Thorpe and Dr. Levinstein. (Applause.)

I remember saying last year that I had studied with extreme care the oratory of my distinguished predecessors, and after having prepared an effort which I thought might perhaps fairly be considered with theirs I looked round this room, and I found the "multitudinous faces of innumerable friends," and in such a case, how could one do more than talk to a number of friends of one's own kith and kin in one's own society? I hope to-night to be able to talk to you as one who has been in the Institution now for some 15 years, and has seen its steady and progressive influence throughout the world, and to say with you, "God speed us!"

In my speech last year I took for a text the words of Plato :— "The aim of a veritable community is not that this or that person should prosper, but that the whole should flourish," and attempted to indicate the value of an Institution like ours to the members as a whole. To-night, before briefly explaining the progress of the Institution during the past year, I would desire to amplify my last year's words from another angle, viz., the service that a member should render to the Institution of which he is a unit.

First of all the individual member should be the best possible recruiting agent. He has been elected to a young and virile society, and naturally wishes that its importance and influence should extend, and with them his own status and prospects. His best course is to bring other suitable candidates forward. Looking around the great technical organisations to-day it is obvious that our numbers should still further increase, and this could be done if each member would make a point of attempting to secure at least one new recruit. So far as I know there has been no serious effort to increase a membership which indeed has gone forward year by year from strength to strength.

We have rather been content to let the aspirant come forward in our old conservative British way. I am not so sure that this is good policy. Surely it should be the aim of us all to make our Institution the one petroleum technical organisation in the world. We are not the I.P.T. of London or of England, or of the Empire. We are THE I.P.T.

A passing thought occurs to me, and that is our definition of a petroleum technologist. Certainly in the past this formidable and sometimes unpronounceable terminology implied a petroleum chemist, a petroleum geologist, or a petroleum engineer, but I am not so sure that nowadays the definition should not be amended and extended to cover a number of cases where the election committee have found some difficulty in placing a candidate. It should be clearly the aim of the I.P.T. to include in its senior ranks everybody responsibly concerned with the development of the petroleum industry in its many complex phases, but there is still scope left to find a place for the general operating personnel in the industry. To this end it may at some future time be desirable to create further grades of membership.

The next way in which the individual can help the whole body is in his support of the Journal. A little later I will deal with this matter in rather more detail, but let me say in passing that we want articles, contributions, notes of interest, personal matter and in general a lively interest in our publications. Fortunately, to-day we have ample matter coming forward, and we should like this kept up and increased so that we can recommend to Council that twelve issues a year, in place of nine, are essential to the welfare of the Institution.

The Journal is the greatest asset of a scientific or technical society. It reaches every member wherever his world-wide service takes him. It keeps him abreast of all modern development and tendencies. It indicates in what direction progress lies. It nourishes and stimulates. It has been a great source of pleasure, gratification and pride to myself that one of the first tasks laid

upon my shoulders by Sir Boverton Redwood was the responsibility for the Institution's publications, and when the time comes for me to lay down the greater responsibility of the presidential office I hope to return to my former duties.

The individual member can help the Institution by assisting in the continued welfare of the Benevolent Fund. Fortunately it is growing and more fortunately the calls upon it are as yet not serious. The Council wishes to see it on a sound financial basis, so sound that in the event of a really serious call it can respond powerfully. As I said last year, we are a young community, and we are starting our fund early. Many societies that I know were compelled by sheer necessity hurriedly to assemble the machinery of charity. We are lucky in anticipating our responsibilities—for responsibilities they are. No society can stand aloof when suffering, poverty, illness and death attack any of its members.

I appeal again, therefore, for your continued support. When you pay your annual subscription, add to it all that you can spare.

Council are immensely indebted to our Senior Past-President, Sir John Cadman, for his timely and characteristic help when he gave 60 guineas to the fund, his emolument for broadcasting his talks on petroleum. It occurs to me that many other members might well devote some "windfall" of this sort to this most desirable object.

I come now to a delicate point. Every year four members of Council retire by rotation and are eligible for re-election. You, as members, have the opportunity of putting forward new nominations. Rarely do you do this. Either you are immensely satisfied with the work of your Council or else the force of inertia has you in its foul grip! No Council can be efficient unless new blood is introduced regularly into its circulation. Transfusion must go on year by year. You are apparently content to be served year in, year out, by the same personnel. Few complaints reach Council, fewer live suggestions are brought forward. The serenity of our meetings might be disturbed but undoubtedly good would come of some measure of active interest—indeed critical interest—in our doings.

I have to record a successful evening spent with our friends of the Oil Industries Club last year. We rather look to the Oil Industries Club and its genial President, Mr. C. Dalley, to provide for the social side, and we welcome their collaboration and wish them all prosperity. I attach some importance to these informal and friendly functions. Just as at the formal technical meetings of the Institution, perhaps the most good comes from the personal contact of men interested in a common subject, so the gathering

together of all sorts and conditions of men interested in the industry as a whole has a value difficult to estimate.

Whilst on this subject I would say a word about the Institution Dinner Club. This Club is select in so far as numbers go. It could and should expand. Any member and his guest are eligible to attend. The dinners follow immediately after the general meetings and are jovial rather than sedate. May I appeal to all members to notify the Secretary in good time that they wish to attend, so that ample provision may be made for their creature comforts.

Recognition ought to be given to the oil companies, great and small, for their continued interest in our work. It is not generally recognised that they make considerable sacrifices in granting facilities for their staffs to participate in our activities. In particular I refer to the work of Council and its multifarious committees. An active member of Council spends a considerable amount of time in committee—time that has to be taken out of his working day. There is no doubt that in return the Institution renders an ever-increasing service to the industry, and that the effect of it on the technical staffs of the companies is more and more pronounced as time goes on.

We now pass to consider the current year's happenings.

First and foremost I must refer to the great loss we have suffered in Sir Frederick Black's death. For more years than most of us can remember he was a tower of strength to the Institution. Whether in the chair in the council chamber, or in committee, he was outstanding in merit, in capacity, in grasp, in kindliness and in courtesy. Distinguished as a man of affairs, he was equally outstanding in matters of science and literature. It may be well said that our Institution has been exceedingly fortunate in finding men of eminence who have given so freely of themselves in its service. Sir Boverton Redwood, Lord Greenway, Sir Frederick Black, Sir Thomas Holland and Sir John Cadman constitute a panel of officers not easily reproducible.

The membership is steadily increasing. Last year at this time there were 1169 members—to-day the figure is 1229, and 50 candidates are awaiting election. The curve is still a linear function of time.

As in previous years the Institution has been represented at the following Congresses :—

Third (Triennial) Empire Mining and Metallurgical Congress, South Africa, March 24th to May 9th, 1930, for which papers were submitted.

International Road Congress, Washington, October, 1930, by Dr. P. E. Spielmann.

World Power Conference, Berlin, June, 1930, by Dr. A. E. Dunstan and Mr. J. Kewley, who presented papers.

Tenth Congres de Chimie Industrielle, Liege, September 7th to 14th, 1930, by Prof. H. I. Waterman, who presented a paper. Representation is also effective on the following bodies :—

The American Society for Testing Materials ; the Advisory Board of the Department of Oil Engineering and Refining of the University of Birmingham ; the British Association for the Advancement of Science ; the British Engineering Standards Association ; the Fuel Economy Committee ; the Imperial Mineral Resources Bureau ; and the Mechanical Warfare Board of the War Office.

As mentioned in my speech last year, the Journal of the Institution is now published in nine parts per annual volume. The sales to non-members are making most gratifying progress, and I think that it is no idle boast that the Journal is increasingly recognised as the leading technical publication in the petroleum industry. International as its reputation already is, I might suggest that a little judicious advertisement of the Journal by members scattered in all parts of the world can only be to its good and to the good of the Institution generally.

Through the Journal the members can serve, not only the Institution, but also the industry at large. There is no dearth of papers submitted, but in order to maintain and enhance the high standing of the Journal it devolves upon the members, and indeed upon all technical men in all branches of the industry, to submit articles and material for consideration by the Publication Committee.

The Institution is particularly indebted to Mr. George Sell, who has for the last eight years been directly responsible to the honorary editor for the production of the Journal. None has the interest of the Journal more at heart than our assistant editor, and I, perhaps, am the person best qualified to bear witness to an unfailing tact and courtesy, combined with unequalled enthusiasm and capacity. (Applause.)

Furthermore, the Institution owes a debt of gratitude to Mr. W. H. Thomas who has been in charge of the Abstract Section for six years. This section continues to supply an extremely useful and much appreciated digest of current scientific and technical literature relating to mineral oil. There is no doubt but that this summary is of especial value to those members who are not in a position to consult personally the increasing mass of published material. Continued appreciation of this section reaches me from every part of the world, and to Mr. Thomas and his able staff of abstractors our thanks are due. At the moment a special sub-committee is sitting to consider how best this valuable side of our proceedings can be further strengthened. (Applause.)

In connection with our publications, reference should be made to the very great success that has attended the second issue of our "Standard Methods of Testing Petroleum and Its Products"—so much so that the Standardization Committee will shortly be faced with the necessity for a third and revised and enlarged edition, and I think I can safely say that the inception of this idea of standardization as an integral part of the Institution's work has been most amply justified. While Professor Brame is here there is no need for me to emphasise the great work which he has done in that connection. We work in close fellowship with the A.S.T.M., whilst our formal and informal contact with our American colleagues is becoming more and more fruitful.

The membership of the branches in Persia, Rumania, South Wales and Trinidad is steadily increasing, and regular meetings are held at which papers are read and discussed. These branches are doing work of immense service to the Institution. The greatest credit is due to the chairmen and officers who keep the flag flying in their own particular and distant territories. These branches are excellent recruiting services and not a little of the continued success of the Journal is due to their efforts. There is no reason why new branches should not continue to be founded.

Members will be pleased to hear that a petition for the grant of a Royal Charter was presented to His Majesty the King in Council in May last, and we have every reason to think that this appeal will be brought to a successful issue. Such a Charter will bring an added dignity and higher status to the Institution and to its members.

Last year I drew attention to the central housing scheme, and since that time much effort has been expended and much progress has been achieved. Quite recently an account was given in the Journal of the progress that has been made, and I may say, in passing, that a Trust, licensed by the Board of Trade, has been formed to take over the executive duties of putting into effect this great and important scheme. Apart from social facilities, which are now deplorably lacking, perhaps the greatest boon that the new House will confer on us all is the combined library.

One complete floor throughout the whole building will contain the General Library. This library will include the libraries already in the possession of the constituent societies, and the 33,000 volumes now in the possession of the chemical societies will be handed over to form the nucleus of the new library. The library will be sectionalised and each section will remain, if desired, under the control of the sectional librarian. In effect, therefore, our library, library commitee and librarian will continue to function in the new building in the same way as they do now, but with greater efficiency.

To my mind the Central Library is one of the chief features of the scheme. It will contain at the beginning some 70,000 volumes, exclusive of pamphlets, and will probably be augmented by some 2000 volumes yearly. The inevitable overlapping between scientific and technical libraries in respect of books and periodicals dealing with borderland subjects will disappear, or, alternatively, will provide duplicate copies which can be utilised for the purpose of lending. There will be an efficient Bureau of Information, by whose aid the enquirer will be directed to the source from which the information he requires can be obtained. In fact, such a library will be unique in its completeness and accessibility and will be a point of attraction, not only for technologists and students at home, but also for those visitors from overseas who desire to keep themselves abreast of modern developments in the subjects dealt with. No one can foresee what effect such a source of information, and indeed of power, housed centrally and easily accessible, may have on the future development of science and industry.

Our own library steadily expands to meet our present requirements, and credit is due to the librarian, Miss Clare Despard, for its continued efficiency. Its usefulness has increased considerably during the past year, and it is consulted daily, either by personal visits, by correspondence, or by telephone. The number of enquiries received from members and other individuals, and from Government and other important concerns, not only in this country but from abroad also, shows a steady increase. The total number for the past year amounts to 1046.

The Institution is indeed well served by its permanent staff. On many previous occasions the President at these functions has emphasised this fact, and perhaps he, who sees the most of the inner workings of the Institution during his time of office, is most fitted to acknowledge the consistent hard work and enthusiasm of the Secretary, Commander R. E. Stokes-Rees, R.N., and his staff. (Applause.)

I, personally, have to thank Council for the honour done me of election to the chair for a further year. When the time comes for me to put off the insignia of office and to hand them over to a more worthy successor, and when I join the distinguished band of Past-Presidents, it will be a continued delight to me to look back on the years of very happy endeavour in the service of the Institution. (Applause.)

"Our Guests."

Professor J. S. Brame, C.B.E., in proposing the toast of "Our Guests," said :—

Mr. President and Gentlemen, I very much regret that I cannot use the words "My Lords and Gentlemen." Unfortunately we

have received letters of regret from Viscount Bearsted, Viscount Cowdray, Lord Wakefield and Lord Melchett. I always think that the toast of " Our Guests " is one which gives to the proposer the greatest possible pleasure. There is a spirit of hospitality, a spirit of friendship with it. As our President has said, we are meeting to-night a large number of old friends at our annual dinner. Not only have we a large number of official friends as our guests, but also a large number of private friends, and the toast of " Our Guests " naturally applies equally to our own individual friends as to our official guests.

The petroleum technologist is probably a peculiar being in the eyes of many of you. Some people are very puzzled as to what a petroleum technologist might be. Of course, we come in touch with applied science, the subject of our first toast this evening, in very many directions. In the very early stages of petroleum finding nowadays the physicist comes along with his geophysical methods. The geologist follows and, after the geologist, the engineer, and, of course, the engineer covers a very wide field. We have the field engineer, who is necessarily more or less of a mechanical engineer; we have the refinery engineer, who is a specialist and is perhaps more or less a chemical engineer. Then we have the automobile engineer. A little further in our process of winning oil we have to consider the metallurgist. Metallurgy, up to the present, I think, has not received the attention that it probably should have received from the oil engineer, but things are improving. We have already had a paper or two relating to metallurgical problems in connection with petroleum technology. Then we come to that distinguished body, the chemists, as the President reminds me. (Applause.) The chemist is a person who bobs up almost everywhere in petroleum technology. We find him pretty busy at the refinery, and at the testing laboratory. I think that the one place where the chemist really finds his sphere of action is in the research laboratory. I am sure that you all realise what a great deal the large oil companies, not only in this country, but in other countries, are doing in promoting research on fundamental problems connected with the chemistry of petroleum.

I have left until the last that very important group of oil technologists, happily represented by very eminent men in our Institution, the financial and administrative heads. It seems a little strange, perhaps, that in an institution of technologists, financial and administrative gentlemen should have found such a scope as they have, or should have been so closely and happily associated as they have been with the more technical sides. These gentlemen, like our Past-President, Lord Greenway, Sir Robert Waley Cohen and others, are men with an outstanding knowledge of the problems

of the petroleum industry, and a surprising grasp of all the technicalities involved. They are, therefore, quite worthy to be accorded the honour of petroleum technologists. When Sir Boverton Redwood, in the year 1913, founded this Institution of Petroleum Technologists he exhibited his usual foresight. He could see the advantage of bringing all these men engaged in the one great industry into association with one another. I think that the results of the work of the Institution have fully justified the anticipations of our revered founder. (Hear, hear.)

Gentlemen, obviously it would be impossible to go through the list of our distinguished guests. I propose very briefly to refer to them more or less under groupings such as those to which I have referred in regard to the membership of the Institution. The physicists we have represented here by Sir Joseph Petavel, of the National Physical Laboratory. At the National Physical Laboratory, as we all know, a great deal of very valuable work has been done for many years past in connection with many problems relating to oil. Unfortunately, the geologists are not represented here to-night, but the engineers are well represented—the Civil Engineers by Mr. Grierson, and the Chemical Engineers by Mr. Reavell and by my old friend Professor Hinchley. Unfortunately the respective Presidents of the Mechanical Engineers, the Mining Engineers and last, but not least, the Automobile Engineers have not been able to attend this evening. We have received letters of apology, and only at the last minute Sir Herbert Austin, the President of the Automobile Engineers, whom we would have welcomed most heartily, has not been able to come. Then we have mining and metallurgy represented by Professor Lawn, and again, I regret to say, another disappointment in the absence of Professor Louis of the Iron and Steel Institute.

We have a number of very distinguished chemists here to-night. Happily the Chemical Society, the premier society in the world, is represented by Professor J. F. Thorpe. We much regret that the President of the Society of Chemical Industry, Lord Melchett, is not present, but we have very great pleasure in welcoming his immediate predecessor, Dr. Levinstein, and we have listened to-night to one of his characteristically humorous speeches. (Applause.) The other large chemical body in the country, the Institute of Chemistry, I regret to say again, is not represented, but a letter of apology has been received from Dr. Clayton.

It is perhaps not altogether inappropriate that the toast of "Our Guests" should be proposed by a humble chemist, since it is coupled with the name of, and it will be responded to by, so distinguished a chemist as Professor J. F. Thorpe, the President of the Chemical Society. (Applause.)

Mr. President and Gentlemen, I have great pleasure in submitting the toast of " Our Guests."

The toast was then enthusiastically honoured.

Professor J. F. Thorpe, C.B.E., F.R.S., in responding to the toast of " Our Guests," said :—

Dr. Dunstan, Professor Brame and Gentlemen, the Master of Sempill and other speakers have referred to the part which I have taken in the promotion of the scheme for a new central building which is to house all the major societies and institutions dealing with the really basic industries and sciences of this country. I should like to say that what small part I have taken in the matter would have been quite useless had it not been for Sir Arnold Wilson. He has been the heart and soul of the whole affair. It is entirely due to his influence, his tact, and the wonderful manner in which he has brought us all together that the success of this scheme is about to be realised. It would be unwise for me at this stage to anticipate in any way the announcement which will be made at the dinner on November 13th, at which the Prince of Wales has very graciously signified his wish to be present as a guest, when the chair will be occupied by the President of the Royal Society. I will say, however, that the societies interested in the scheme will in not the slightest degree lose their autonomy. They will remain definitely and distinctly themselves, and they will retain in every way the autonomy which they possess at the present time. (Hear, hear.) The great feature of the whole scheme is that we shall all be brought together, and we shall all meet. We shal have one common library, which will be the finest scientific library in the world, and we shall also have connected with this scheme a club and premises where we can meet together and generally discuss our difficulties, and adjust all matters.

With reference to the remark which Dr. Levinstein made with regard to the economic conditions in the petroleum industry, I remember that I had to reply to a toast at the Institution of the Rubber Industry. I then pointed out that they were committing a grave mistake in making their materials too good. What they had to do was to prepare a motor tyre which would last for 5000 miles and no more, and then, of course, all would be right. Some one said : " What about those people outside who can manufacture tyres which will last for more than 5000 miles ? " Of course, in a few years' time we shall be able to deal with that sort of thing quite easily.

Sir, on behalf of all the guests I should like to thank you for your excellent hospitality, and to express the hope that you will ask us again. (Applause.)

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND TWENTY-NINTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts, John Street, Adelphi, London, W.C., on Tuesday, October 14th, 1930, Dr. A. E. Dunstan, President, occupying the Chair.

The Secretary read the names of members elected and candidates nominated for election since the last General Meeting as follows :—

The following were elected on May 30th, 1930 :—

As Members.—Robert Allan, Louis Alfred Bushe.

As Associate Members.—Almon Lee Beall, Harry Dobson, Raymond Wilson Dunster, Max Metsch, Donald Gray Phelps, Terence Charles Richards.

As Transference to Associate Member.—William Edmund Madden, Ian McCallum.

As Students.—Herbert Harland, Robert Edgar Moore.

As Associates.—William Henry Bailey, George John Hancock.

The following were nominated on May 2nd, 1930 :—

As Transference to Members.—Francis Roger Spencer Henson, Niels Matheson.

As Associate Members.—George Barclay, David Neill McKinlay, Kenneth Arthur Spearing, Arthur Augustus Weir.

As Transference to Associate Member.—Donald Thomas Jones.

As Student.—Willem Jan Hessels.

The following were nominated on September 3rd, 1930 :—

As Members.—William Ernest Victor Abraham, George Calzavara, Andre Graetz, George Hulme Hubbard, Theodore Alaric Peck, Francis Martin Potter.

As Transference to Member.—Albert Harold Seagrim, Henry N. L. C. E. C. de Wilde.

As Associate Members.—Jean Georges Berteloot, Max Capper, Eric Carter, Stanley Owen Connor, Norman Russell Fowler, Donald George Hitt, Thomas Reginald Palmer, Robert George Perry, Walter Sigg, Colin McLuckie White.

As Transference to Associate Member.—Maurits Julius Bernard de Blank, Douglas Jonathan Pull, Jesse Ossowa Tanner.

As Associates.—Douglas Oliver Bremner, George Norton Critchley, Alexander P. Shearer, Thomas Gilbert Webb.

The following were nominated on October 3rd, 1930:—

As Member.—Robert Webb Farmborough.

As Associate Members.—George Philip Bowring, Leslie Vincent Woodhouse Clark, (Miss) Winifred Sarah Elizabeth Clarke, Noel William Grey, Ernest Noel Hague, Arthur Noel Lucie-Smith.

As Transference to Associate Member.—George Dickinson.

As Students.—John Greaves Beastall, Richard Vernon Browne, John Leslie Howard, Geoffrey Howard Hunter-Brown, John Alexander Pryde, Tadeusz Rudolf Rogala.

As Associate.—Roland Doumin.

The President welcomed the members and guests on this, the first meeting of the session, and said that as Mr. Glyde was ill and in hospital, Mr. Alcock had kindly come forward to present the paper in his place. He then called upon Mr. J. F. Alcock to read the following paper:—

Experiments to Determine Velocities of Flame Propagation in a Side Valve Petrol Engine.

By H. S. GLYDE, B.Sc., A.M.Inst.C.E.

PURPOSE OF THE EXPERIMENTS.

The following paper gives an account of some experiments made by the writer to determine the velocity of flame travel in an internal-combustion engine of the side-valve poppet type. Tests were carried out on a conventional type of head, as shown in Fig. 1, in order to investigate flame velocities in a combustion chamber in which the degree of turbulence was relatively low. In addition, measurements were taken for combustion chambers of the Ricardo turbulent type having three different head clearances, viz.—0·022, 0·084 and 0·272 in. Fig. 2 gives a sketch of head No. 6, in which the head clearance was 0·272 in.

It had been found that in the Ricardo type of combustion chamber the head clearance had a very marked and critical effect on detonation (see Fig. 3). The curve of H.U.C.R. plotted against head clearance showed a very abrupt change in characteristic at a head clearance of approx. 0·14 in. It appeared that below a certain clearance the surface volume ratio of the gas trapped above the piston became great enough to militate against self-ignition and the occurrence of detonation. It was thought that an attempt to investigate the velocity of flame movement in head clearances of different depth might throw some light on this phenomenon. Further, variation in head clearance gave rise to changes in the degree of turbulence, so that the velocity of flame travel across the combustion chamber under different conditions of turbulence might also prove of interest.

Apparatus.

The apparatus consisted essentially of a side-valve single-cylinder engine (see Figs. 4 and 5)—bore, 4 in.; stroke, 6 in.—having a cylinder capacity of 1·24 litres. The inlet valve throat diameter was 1⅜ in., giving a mean gas velocity of 137 ft. per sec. at 900 r.p.m., the speed at which the experiments were carried out. Owing to the high gas velocity through the inlet valve, the degree of turbulence was unusually high, so that the rate of pressure rise for the combustion chamber of conventional type shown in Fig. 1

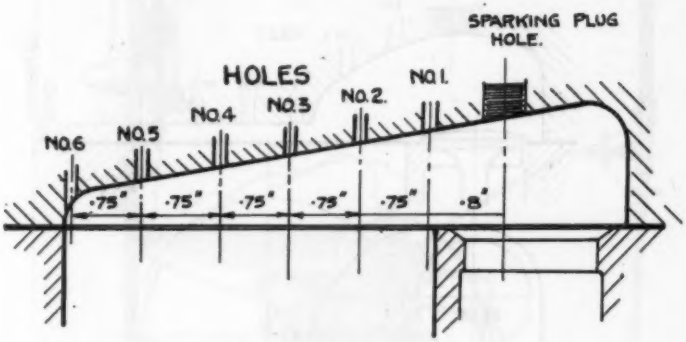

Fig. 1.

was as high as 23 lb. per sq. in. per degree. Arrangements were made for running the engine with an open water jacket, so that the castings of the various combustion chambers tested were much simplified and could be readily changed by bolting them down to the cylinder block inside the water jacket.

Each head casting was fitted with six sight holes through which to watch the time and travel of the flame across the combustion chamber. Fig. 2 gives sectional and plan views of a typical combustion chamber fitted with sight holes. These holes, which were fitted with glass windows, stretched in a straight line from the sparking plug to the furthest point of the clearance space. The first hole was 0·8 in. from the centre of the sparking-plug hole—*i.e.*, from the initial spark nucleus—while all the other spaces between holes were 0·75 in. in length. The hole furthest from the sparking plug was ⅛ in. from the combustion-chamber wall on the far side. The flame travel was therefore examined over a distance of 4·55 in. from the spark to the last hole.

On a vertical shaft driven through a skew gear from the horizontal ignition timing shaft revolved a disc of 16 in. diameter,

This diameter was large enough to allow of the exact coincidence of a number of holes cut in it in a straight line radiating from the centre, with the holes in the combustion chamber. The disc was provided with an adjustable timing arrangement in which the relative positions of the skew gears could be adjusted by means of a screw. By the regulation of this screw the exact time of coincidence between the two sets of holes could be adjusted to any desired timing within a range of about 60° of crankshaft movement. It is easily seen that by varying the timing of the

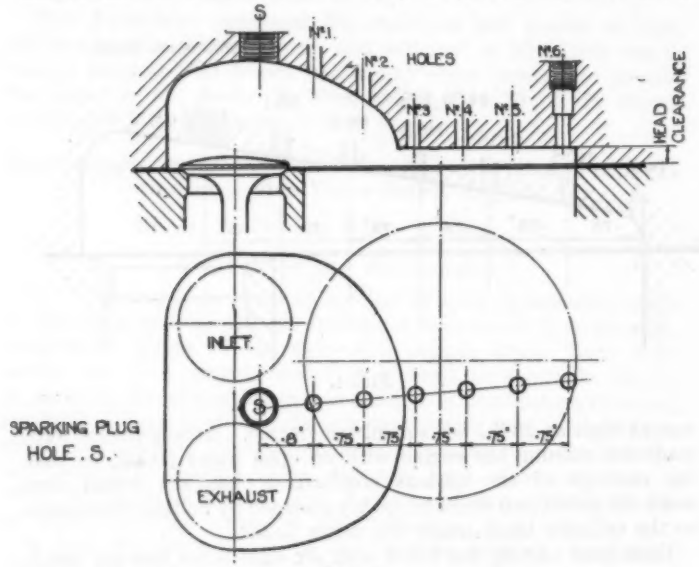

FIG. 2.

disc in this way the actual time in crankshaft degrees of flame travel from point to point across the combustion chamber could be determined.

Full provision was made for taking readings of the speed, power output, fuel consumption, and ignition advance during the tests. Indicator diagrams showing the variations of pressure in the cylinder were taken simultaneously with stroboscopic disc readings and, for this purpose, an R.A.E. indicator was used.

METHOD OF CARRYING OUT THE TESTS.

The engine was set running at the required mixture strength, the spark advance being always carefully adjusted to give the best

FLAME PROPAGATION IN A SIDE VALVE PETROL ENGINE.

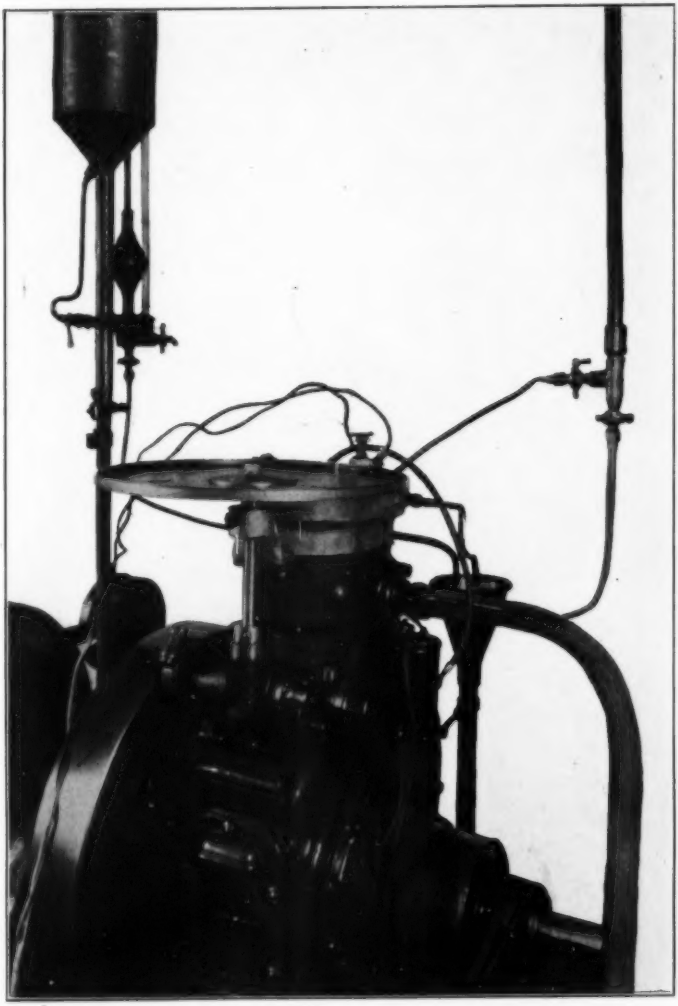

Fig 4.

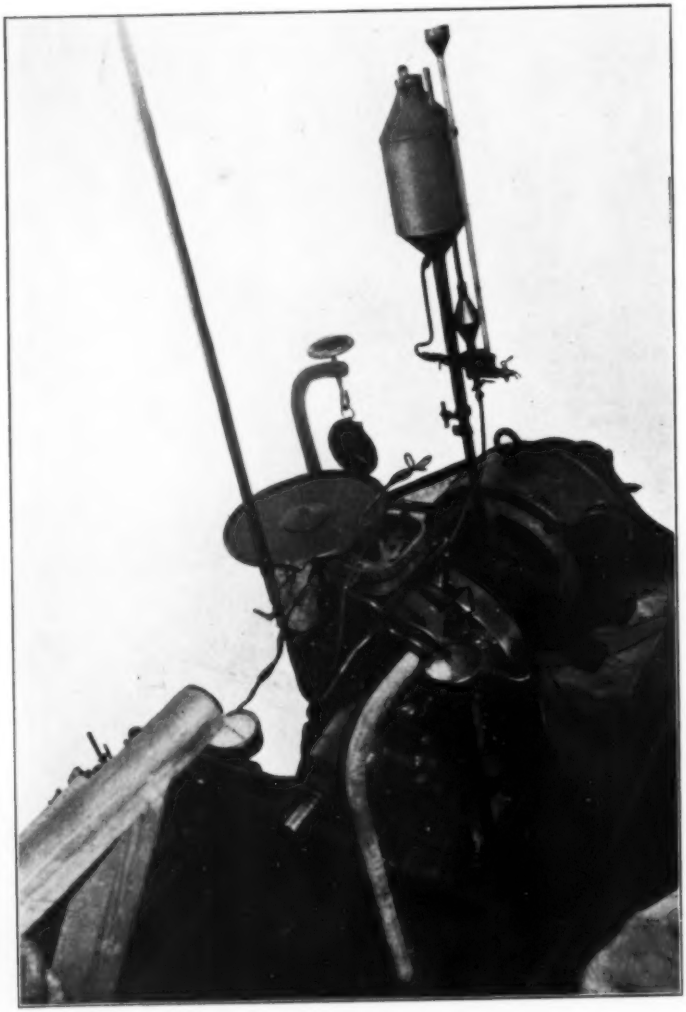

FIG 5.

power output. Readings of the stroboscopic disc and all other engine readings such as speed, torque, fuel consumption, ignition advance and water temperatures were taken simultaneously. At each engine setting indicator diagrams were taken by another observer while the adjustments and readings of the stroboscope were in progress.

The method of measuring the velocity with which the flame front travels across the combustion chamber from the sparking plug points to the further side of the piston, *i.e.*, from S to hole No. 6 (see Fig. 2) was as follows: First of all, engine conditions having been carefully fixed as desired, the timing of the disc was so

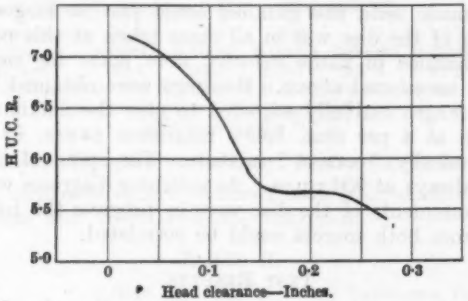

FIG. 3.

adjusted that all the glass windows, six in number, were showing a clear white light. This means that the holes in the disc were immediately above the holes in the combustion chamber at some time after the flame had traversed the whole length of the combustion chamber. The timing of the disc was then advanced very slowly by means of the adjusting screw until the light showing in No. 6 hole just disappeared. The disc was now in such a position that the flame was just reaching No. 6 hole. The timing of the disc in this position was carefully recorded and the adjusting screw further advanced until the light just disappeared in No. 5 hole. A reading of the disc timing was again taken and recorded. This process was repeated until disc readings had been taken of all six holes so that a complete series of times was obtained expressed in crankshaft degrees before and after T.D.C. at which the flame passed each hole in its progress across the combustion chamber. The reason for reading, for each hole, the time of disappearance rather than the time of appearance of the flame will be clear when it is explained that it was easier for the observer looking down into the sightbox with the naked eye to decide when he could just no

longer see the flame than it was to pick up or catch sight of the faint glimmer of light which is at first seen when the disc is slowly retarded.

What was actually seen by the observer was roughly as follows :— At first, when all the six holes were showing, there were to be seen six discs of light. Generally speaking No. 1 hole was very pale but quite distinct, while No. 6 hole was showing a yellow flame. Intervening holes gradually merged into these two extremes of colour. On advancing the disc No. 6 hole slowly became less and less distinct and probably intermittent until there remained only a very faint glimmer of light visible, say, on one out of every three explosions of the engine. A further small advance of the disc was then made until this glimmer could just no longer be seen. The timing of the disc was in all cases taken at this point.

Determinations of flame velocity were made for each of the four heads mentioned above. Readings were obtained both at a mixture strength carefully adjusted to give the maximum power output and at 4 per cent. below maximum power, *i.e.*, at very nearly chemically "correct" mixture. The speed of the engine was kept always at 900 r.p.m. As indicator diagrams were taken while measurements of the disc were in progress the information obtained from both sources could be correlated.

Test Results.

The following are the stroboscopic disc readings for the various heads tested.

Head No. 1. Record I.

	S to No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Degrees of Crankshaft	14·05	5·9	2·25	2·7	2·95	3·4
Time in seconds ..	0·0026	0·00099	0·00042	0·0005	0·00055	0·00063
Velocity in ft./sec. ..	25·6	57·0	150	125	114·4	99·2

Full throttle 900 R.P.M. B.M.E.P. 105·5 lbs./sq. in.
Fuel consumption 0·600 pts./B.H.P.—hr.
Ignition advance 11·4° E.

Record II.

Degrees of Crankshaft	18·3	3·55	3·25	4·55	3·45	2·25
Time in Seconds ..	0·00340	0·00066	0·00060	0·00083	0·00064	0·00042
Velocity in ft./sec. ..	19·7	95·2	104·0	74·3	97·8	150·3

Full throttle 900 R.P.M. B.M.E.P. 100·5 lb./sq. in.
Fuel consumption 0·546 pts./B.H.P.—hr.
Ignition advance 16° E.

Head No. 2. Head Clearance 0·022″ Record III.

Degrees of Crankshaft	5·5	4·5	2·3	1·4	1·3	3·9
Time in seconds ..	0·00012	0·00083	0·00042	0·00026	0·00024	0·00027
Velocity in ft./sec. ..	65·4	75·1	147	242	260	86·5

Full throttle 900 R.P.M. B.M.E.P. 105·2 lb./sq. in.
Fuel consumption 0·695 pts./B.H.P.—hr.
Ignition advance 5·3° E.

RECORD IV.

Degrees of Crankshaft	9·7	6·7	2·6	1·0	1·0	5·3
Time in seconds ..	0·00180	0·00124	0·00048	0·00018	0·00018	0·00098
Velocity in ft./sec. ..	37·1	50·4	130	338	338	63·8

Full throttle 900 R.P.M. B.M.E.P. 100·6 lb./sq. in.
Fuel consumption 0·575 pts./B.H.P.—hr.
Ignition advance 13° E.

HEAD No. 3. HEAD CLEARANCE 0·084" RECORD V.

	8 to No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Degrees of Crankshaft	11·1	3·9	2·8	1·0	1·8	4·1
Time in seconds ..	0·00206	0·00072	0·00052	0·00018	0·00033	0·00076
Velocity in ft./secs. ..	32·5	86·4	120·5	338	187·3	82·3

Full throttle 900 R.P.M. B.M.E.P. 106 lb. per sq. in.
Fuel consumption 0·693 pts./B.H.P.—hr.
Ignition advance 9·4° E.

HEAD No. 6. HEAD CLEARANCE 0·272" RECORD VI.

Degrees of Crankshaft	11·8	3·6	1·3	1·1	3·7	4·0
Time in seconds ..	0·00218	0·00067	0·00024	0·00020	0·00069	0·00074
Velocity in ft./sec. ..	30·4	93·7	259·5	307·5	91·2	84·3

Full throttle 900 R.P.M. B.M.E.P. 109·5 lb./sq. in.
Fuel consumption 0·660 pts./B.H.P.—hr.
Ignition advance 10° E.

Table I on page 762 gives performance figures for the heads tested.

Table II compares figures obtained both from stroboscopic disc measurements and from indicator diagrams.

TABLE II.

		DISC.				INDICATOR DIAGRAMS.		
Head No.	Ign. Adv. ° E.	Total time to No. 6 hole. deg.	Total time to No. 6 hole. secs.	Mean vel. over whole distance.	Max. vel. attained over ¼in. interval.	Total time spark to max. press. deg.	Total time spark to max. press. sec.	T.D.C. to peak of diagram.
1	11·4	31·25	0·0058	65·6	150	25·9	0·0048	14·5
2	5·3	18·9	0·0035	108·3	260	23·3	0·0043	18·0
3	9·4	24·7	0·0047	82·8	336	24·4	0·0045	15·0
6	10	25·5	0·0047	80 2	307	26·2	0·0048	16·2

NOTES ON THE TESTS.

1. *Fuel.*—All the tests were run on the same fuel in order to keep conditions as constant as possible. The fuel used was a straight run petrol of fairly high aromatic content having an S.G. of 0·786 at 15° C. and an H.U.C.R. of 5·85 : 1 as tested in our variable compression engine. It was thought that by using this fuel and by adopting a standard C.R. of 6 : 1 complications such as the occurrence of detonation which would upset the results would be eliminated.

TABLE I.

Head No.	Compression ratio.	Mean Effective Pressure.		Minimum Fuel Consumption.		Ignition advance °E.	Rate of Pressure. rise. lbs. per sq. in. per degree.	Maximum Pressure. lbs. per sq. in.	H.U.C R.
		Brake lbs. per sq. in.	Indicated	Brake Pts./H.P. hour.	Indicated				
1	5.1 : 1	105·5	123.0	0.545	0.479	11.4	23.3	420	5.2
2	5.1 : 1	105.1	118.3	0.567	0.494	5.3	58.7	430	>6.8
3	5.15 : 1	106.1	119.9	0.561	0.483	9.4	38.5	429	6.8
6	5.31 : 1	109.4	123.0	0.534	0.467	10.0	34.1	461	5.4

2. *Lubricating Oil.*—The same lubricating oil was used throughout and as the engine was provided with a long skirt cast-iron piston, very little oil found its way to the combustion chamber.

3. *Sight box and size of holes in disc.*—It was found that in order to see all the holes clearly, it was necessary to make slots in the disc of rectangular form with the longer side lying radially. Circumferentially, for the purpose of accurate disc timing the slots in the disc were exactly the same width as the holes in the head.

Further, in order to see the lights in the windows clearly it was found to be necessary to paint the disc black and to erect a sight box through which to look when taking readings. This took the form of a vertical elliptical tube about 9 in. high, of such section that all the holes could be seen at once. At the bottom edge the tube was surrounded by a band of canvas, always in contact with the moving disc, to keep light from getting through the necessary clearance between the stationary sight tube and the rotating disc. This arrangement proved to be quite effective, practically no reflected daylight being seen inside the tube when the observer was watching the flame through the holes.

4. *Glass windows.*—The windows which were made up of cylinders of glass sealed top and bottom by lead washers showed a vigorous tendency to soot and great care had to be exercised not to run for any length of time on a mixture richer than maximum power.

5. *Method of giving periods of time in degrees.*—It should be remembered that all the above tests were carried out at an engine speed of 900 r.p.m. and that in considering periods of time the method of using a degree movement of the crankshaft is mainly adopted. For comparison with and consideration of higher speeds of running, although the actual times taken for similar changes and phenomena in the combustion process are actually shorter, the times, as measured in degrees of angular movement of the crankshaft, would probably be substantially the same.

Figures.

In addition to the above tables, the results of the tests are shown graphically in Figs. 6–19. Figs. 6, 7 and 8 give curve of the velocity of flame movement plotted against time in relation to the crankshaft and against distance of travel. Fig. 9 co-relates time plotted as crankshaft degrees before or after T.D.C., with distance of flame travel, and Fig. 10 shows the time interval from the occurrence of the spark to the passage of the flame under each hole in the combustion chamber. Incidentally, of course, in the time taken for the flame to reach hole No. 6 we have an indication of the total time over which the whole process of combustion is taking

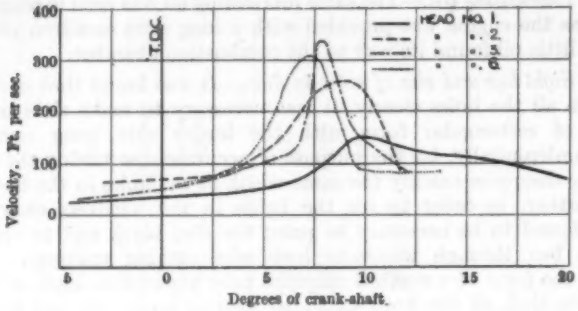

FIG. 6.

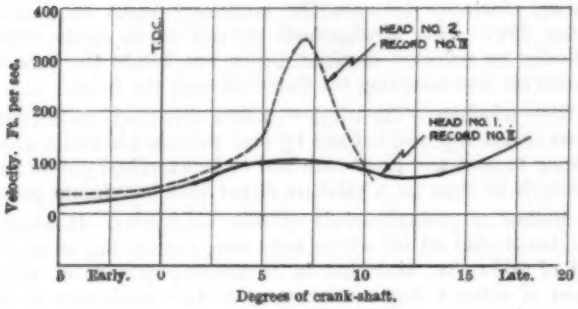

FIG. 7.

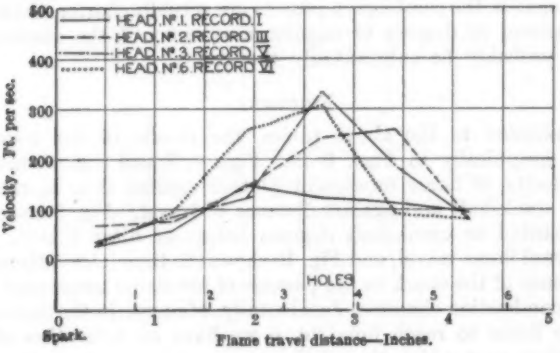

FIG. 8.

place. The remaining Figs. 11–19 show curves of flame travel and cylinder pressure plotted against a common base, viz., degrees of crankshaft before and after T.D.C. as well as certain interesting relationships in Figs. 18 and 19.

Discussion of the Results.

From Figs. 6–8 it will be seen that all the curves have the same characteristic in that there is at first a period immediately after the occurrence of the spark when the velocity is relatively low. Subsequently the velocity rises rapidly to a maximum value and then falls off until the further side of the combustion chamber is reached.

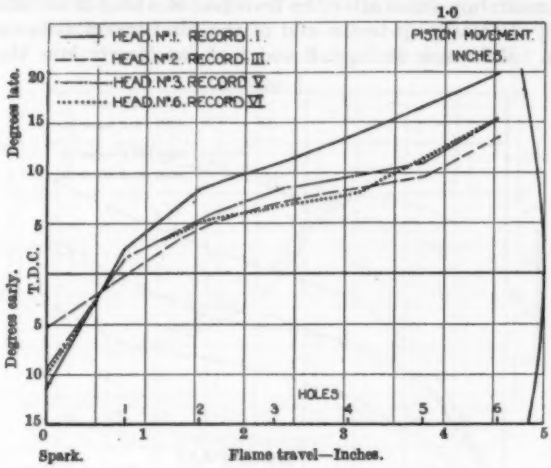

Fig. 9.

It will be noticed that in every case the time of occurrence, in relation to the crankshaft of maximum velocity is within a very close range, viz., from 7–10° after the top dead centre. Reference to Figs. 11–17 shows that in relation to the indicator gas pressure diagrams the time 7–10° L. represents a condition when the rate of pressure rise is at its maximum value so that the flame front is moving at its greatest velocity when the rate of pressure rise is greatest.

The maximum velocity attained in Head No. 2, Record III, is not so high as for Heads Nos. 3 and 6, although in these cases the rate of pressure rise is lower. This, at first sight, would seem to be an anomaly, but examination of the figures shows that the spread of

flame is, in Head No. 2, in the early stages exceptionally rapid and before there is time for the velocity to reach the higher maximum values of Heads Nos. 3 and 6 the flame has reached the head clearance. In the case of Head No. 2. the depth of head clearance was only 0·022 in., in which, apart from mechanical disturbance, flame could only spread quite slowly owing to the high surface-volume ratio and the consequent chilling of the gas contained therein.

In terms of actual distance it is seen that the velocity of travel is relatively low and the acceleration is slow up to a distance of 1·55 in. from the sparking plug; the velocity then increases rapidly to its maximum value after the traversal of about 3 in., when the velocity decreases up to the end of the total travel distance, viz., 4·55 in. Reference to Figs. 6 and 8 shows clearly how the head

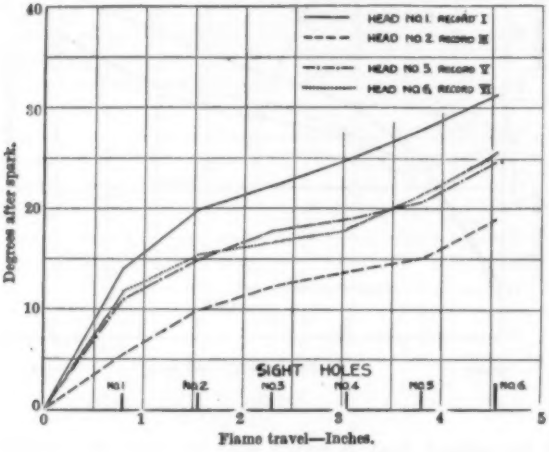

FIG. 10.

clearance slows up the movement of the flame, particularly in Heads Nos. 3 and 6. Whereas in Head No. 3, say, the velocity falls from 340 to 90 ft. per sec. from Hole No. 3 to Hole No. 6, in the case of Head No. 1 in which there is no attempt at reducing the head clearance (Fig. 1) the velocity falls only from 150 to 100 ft. per sec. Again, the curve for Head No. 2 does not quite fall in line with the others, for a velocity of 250 ft. per sec. is maintained for about an inch of travel in a head clearance of 0·022 in.; probably the only explanation which can be put forward for this is that the high degree of turbulence prevailing

in Head No. 2 causes the bodily movement at high speeds of portions of the charge. The direct result of this would be that a mass of incandescent gas is moved rapidly in the head clearance towards the far side of the piston: alternatively it may be that despite the chilling effect and the extremely shallow nature of the head clearance the turbulence is high enough to cause at first rapid burning. In the extreme isolated portion of the head clearance however, see Fig. 8 (from 3·5 to 4·5 in. from the sparking plug), there is no doubt about the velocity damping effect of the head clearance in this head, as it is seen that the velocity falls from 260 to 85 ft. per sec.

It is interesting to notice (see Fig. 9) that although there is a difference of about six degrees in the time of occurrence of the spark, yet after the flame has travelled in all cases about 0·6 in.

RECORD I.

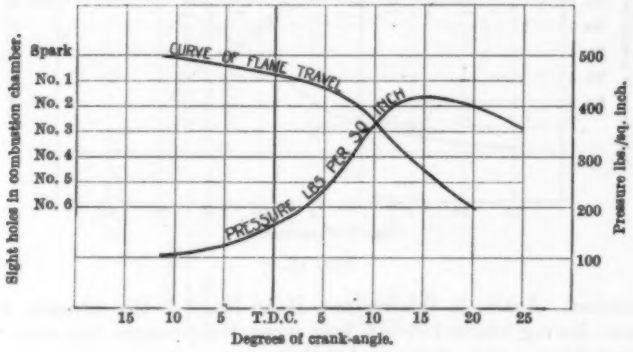

FIG. 11.

the same point in time is reached. It is curious that the curves all cross at the same point.

The difference between the curves of flame travel and between indicator diagrams for a head of comparatively low turbulence and a head having a degree of turbulence giving the best results is shown in striking manner in Fig. 17, where the curves are superimposed for comparison.

A curve of the mean velocity for the whole distance of flame travel plotted against rate of pressure rise is shown in Fig. 18. The points lie on a straight line. The points of maximum velocity, setting aside Head No. 2, which, as explained above, does not fall in line with the other heads in this respect, also appear to approximate to a straight line, although the number of points available is too small to permit of the drawing of a definite curve.

Other relationships are shown in Fig. 19. It is seen that the points both for the total time and the time taken from the sparking plug to No. 1 hole plotted against rate of pressure rise lie on fair curves indicating that the velocity of flame travel is approximately proportional to the rate of pressure rise even from the occurrence of the spark.

Consideration of the indicator diagrams of cylinder pressures shows that the peak of the pressure is reached at the same time as the flame reaches the end of its travel across the combustion

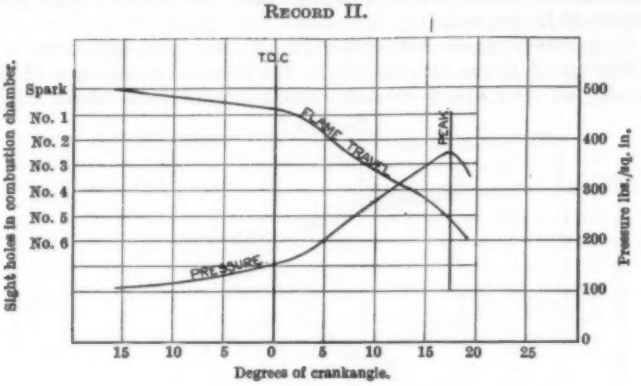

FIG. 12.

chamber. Again, in this respect, Head No. 2 is the offender, the flame having reached No. 6 hole when the pressure has risen to about 75 per cent. of its peak value.

Table III page 769 compares the curves of flame velocity with the indicator diagrams.

One feature of the following results (Table III) is the close similarity between the figures obtained for Heads Nos. 3 and 6, of which the rates of pressure rise were respectively 38 and 34 lb. per sq. inch. per degree. The flame has travelled in both cases approximately 2·3 in. before the explosion pressure line (to which the rates of pressure rise quoted refer) has started. After travelling only 0·4 in. more, to a distance of 2·7 in., maximum velocity is reached. We see, therefore, that the flame reaches its maximum velocity immediately after the beginning of the explosion line, i.e., after the curve leaves the sharp radius with which the compression is connected with the explosion line. In Head No. 1 a head of comparatively low turbulence, the results are similar to Heads Nos. 3 and 6 but owing to the slower movements of the gases the

TABLE III.

Head.	Ignition advance °E.	Explosion line starts.		Maximum Velocity.			Peak of diagram °L.	Rate of pressure rise. lb. per sq. in., per degree.	Maximum pressure, lb. per sq. in;	Maximum velocity, ft. per sec.
		Degree.	Distance from sparking plug of flame in.	Degree °L.	Distance in.	Pressure lb./sq. in.				
1	11.4	T.D.C.	0.8	8½–11	1.95	315	14.5	23	420	150
2	5.3	10° L.	3.8	8½–9½	3.45	143	18	59	430	260
3	9.4	8.5° L.	2.3	8½–9½	2.7	190	15	38	430	337
6	10.0	6.7° L.	2.3	7 –8	2.7	210	16	34	460	307

attainment of maximum velocity is somewhat delayed and the pressure has risen to 315 lb. per sq. in. before this point is reached. It is interesting to note that the pressure rise line begins much earlier in this case after a flame travel of only 0·8 in., but in point of time considerably later owing to the slow initial velocity of the flame.

RECORD III.

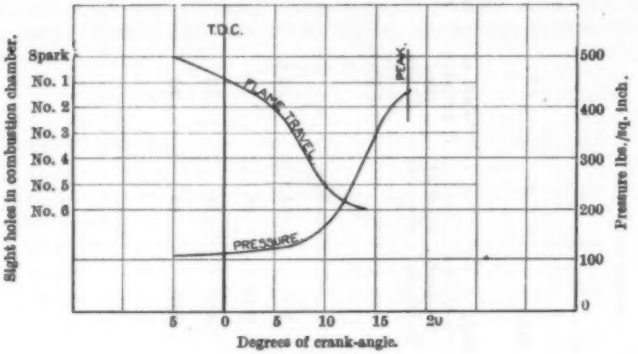

FIG. 13.

The following table shows the time in degrees which elapses after the spark occurs until the beginning of the main explosion pressure line.

	Degrees.	Rate of pressure rise.
Head No. 1	11·5	23 lb./sq. in./deg.
,, 2	15·3	59 ,, ,,
,, 3	18	38 ,, ,,
,, 6	16·7	34 ,, ,,

DETONATION.

It will be noticed from Fig. 8 that both in the case of Head No. 6, in which the head clearance was 0·272 in. and in the case of Head No. 3, in which the head clearance was 0·084 in., the velocity of flame travel when the flame enters the head clearance is damped down to a similar extent for each depth of head clearance. This indicates that a head clearance of 0·272 in. has a damping effect on the velocity of flame travel equivalent to that due to a head clearance as small as 0·084 in. There is, however, an enormous difference in H.U.C.R. between the two heads which very strongly suggests that as there is no difference in the slowing up of the flame in either instance, the discrepancy in H.U.C.R. may

be attributed to the difference in the surface-volume ratio of the volume enclosed by the head clearance above the piston. In Head No. 6 (head clearance 0·272 in.) the surface volume ratio of

[RECORD IV.

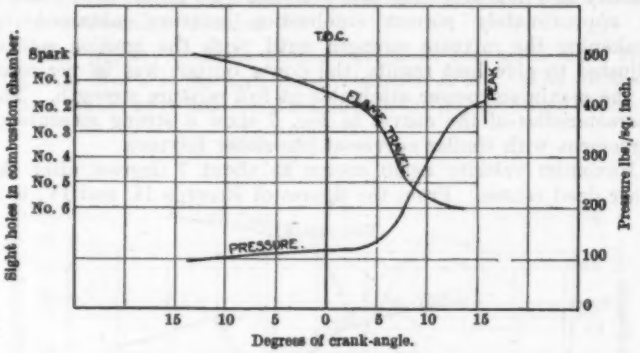

FIG. 14.

the unburnt portion of gas on the far side of the piston is small compared to the similar portion in Head No. 3 so that in the case of Head No. 6 the unburnt volume of gas is able to a much less

RECORD V.

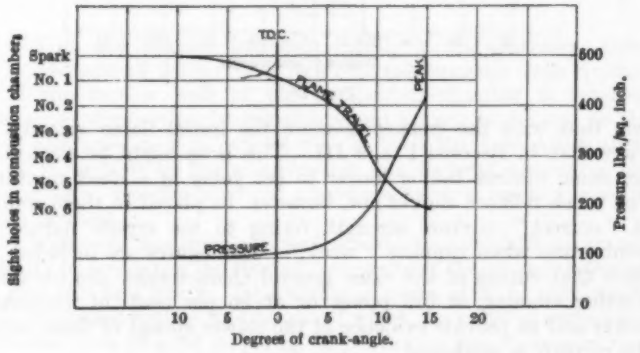

FIG. 15.

extent to get rid of its heat to the walls of the combustion chamber. Consequently when the temperature of the gas on the far side of the piston is raised by compression from the burnt gas and

radiation from the advancing flame front, other things being equal detonation will occur the more readily in Head No. 6 than in Head No. 3. This, it will be observed, is actually the case.

Figs. 7, 12 *and* 14, *Records II. and IV.*—Measurements of flame velocity and indicator diagrams were taken on Heads Nos. 1 and 2 at approximately correct combustion mixture, obtained by weakening the mixture strength until, with the ignition setting adjusted to give best results, the power output was 96 per cent. of the maximum power attainable at full mixture strength. The characteristics of the curves in Fig. 7 show a strong measure of agreement with similar curves at the richer mixture.

Maximum velocity again occurs at about 7 degrees after the inner dead centre. From the figures of Records II. and IV. it is

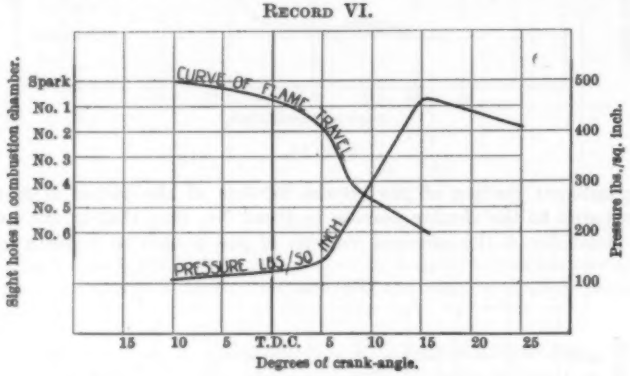

FIG. 16.

seen that with the weaker mixture the initial flame velocity is lower than in Records I. and III. This is as might be expected, the flame nucleus taking longer to get going in a weak mixture. Too much reliance should not, however, be placed in these results at "correct" mixture strength owing to the erratic nature of combustion when running "weak." The figures are included to show that curves of the same general characteristic are obtained whether running at full power or at 96 per cent. of maximum power and to provide evidence of the slower spread of flame when the mixture is weakened.

GENERAL CONCLUSIONS.

1. The greater the degree of turbulence, the greater both the mean and the maximum velocity of flame travel across the combustion-chamber. Velocity of flame travel is almost proportional

to the degree of turbulence as measured by rate of pressure rise on the explosion line of the pressure diagram. It should be noted that this conclusion applies only to heads having the same general form, and in which all variables are kept as nearly as possible the same with the exception of the degree of turbulence in the combustion-chamber.

2. The velocity of flame propagation is at first quite slow, and until hole No. 2 is reached the acceleration is low (The distance of flame travel up to hole No. 2 is 1·55 in.). After reaching a distance

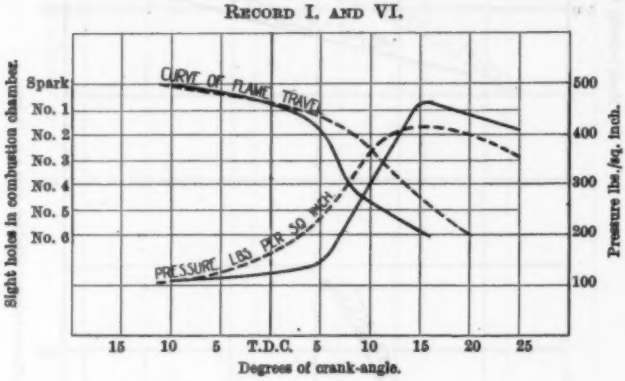

FIG. 17.

of 1·55 in. the velocity increases rapidly to its maximum value at a distance of 2·7 in. The velocity subsequently falls quickly until the further wall of the combustion-chamber is reached. The rapid diminution in velocity would appear to be due to the head clearance, as it is noticed that in head No. 1, in which there is no restriction to flame movement due to head clearance, the falling off in velocity after the maximum value is reached is much more gradual.

3. Whatever the degree of turbulence, the time at which maximum velocity occurs, when the time of occurrence of the spark is adjusted to give the best results, falls within a range of 3° of crankshaft. This statement applies to 4 heads, of which the range of turbulence extended from 23 to 59 lb. per sq. in. per degree rate of pressure rise.

4. The velocity with which the flame spreads from the nucleus of No. 1 hole—*i.e.*, the first 0·8 in. of the distance of travel—is nearly proportional to the degree of turbulence as measured by rate of pressure rise (see Fig. 19, in which the time in degrees is plotted against rate of pressure rise). This was an unexpected

feature of the results, as it was thought that the rate of flame propagation in the initial stage of combustion would have been more or less constant over a wide range of turbulence on the assump-

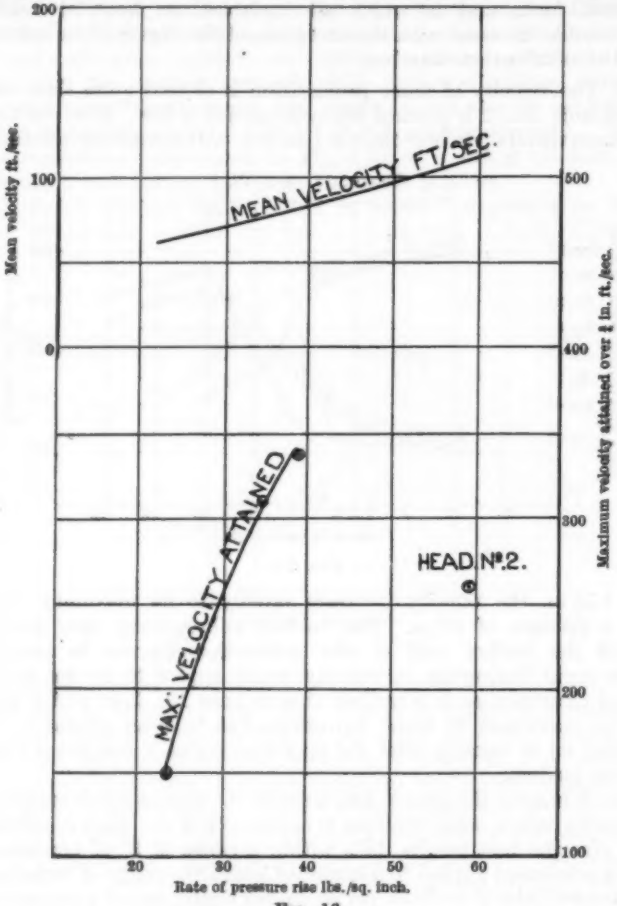

FIG. 18.

tion that at first when the flame nucleus is in process of development, the spread of flame would not be dependent on the degree of turbulence, but on the strength of mixture surrounding the sparking-plug points.

5. The total time for the flame to traverse the full distance from the sparking plug to the opposite side of the piston (see Fig. 19) is also nearly proportional to the rate of pressure rise.

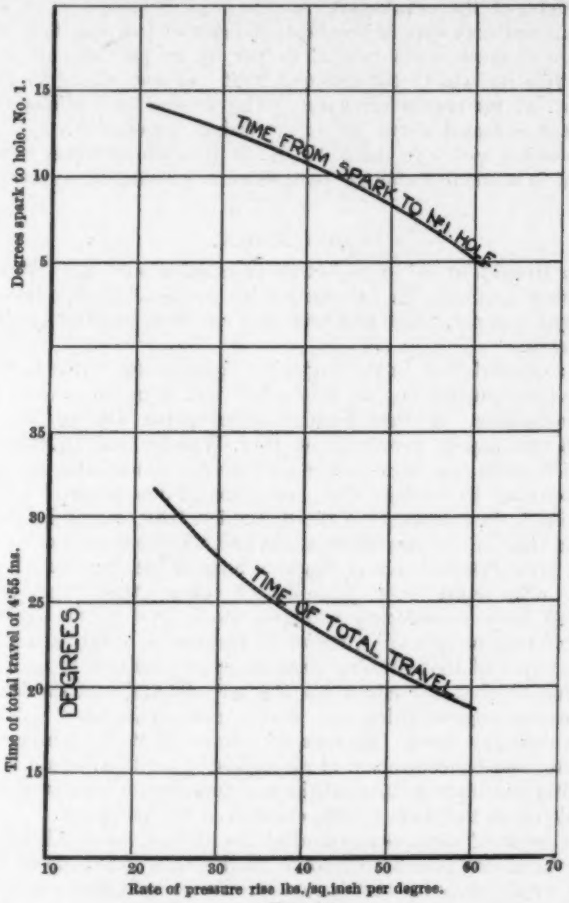

FIG. 19.

6. Broadly speaking, for combustion-chambers of the Ricardo Turbulent type (see Fig. 2), with a rate of pressure rise of from 30-40 lb. per sq. in. per degree (the degree of turbulence usually employed in practice), the flame velocity may be said to be of the

order of 30 ft. per second initially, rising to 300 ft. per sec. during the combustion process. The period occupied by the process of combustion corresponding to these velocities is about 25° angular movement of the crankshaft.

In the ordinary type of combustion chamber (see Fig. 1) in which the rate of pressure rise was 23 lb. per sq. in. per deg., the initial flame velocity was of the order of 25 ft. per sec., rising to 150 ft. per sec. at its maximum value. The process of combustion in this case occupied about 30° of crankshaft movement.

The writer wishes to thank Mr. H. R. Ricardo, of whose research staff he is a member, for his permission to publish these results.

DISCUSSION.

The President said that before proceeding with the discussion he wished to thank Mr. Alcock for his excellent interpretation of Mr. Glyde's paper, which had been very concisely put and admirably illustrated.

He supposed that in dealing with propagation of flame in the internal combustion engine, no Society had done more work than the Institution of Petroleum Technologists. During the last session two papers were read by Prof. Wheeler and Dr. Maxwell, in which there was brought forward a very remarkable theory of after-burning to explain the phenomena of detonation. Perhaps Mr. Alcock, in summing up the discussion later, might be able to refer to that interesting observation, and tell the members whether it had been observed in any shape or form in the Shoreham laboratories. One must bear in mind, of course, that Wheeler and Maxwell were considering rather a static system as against a dynamic system, and the question of turbulence hardly arose.

The paper of that evening gave an approximation to an understanding of what one might call the aero-dynamics of the internal combustion engine, using the word "aero-dynamics" not quite in the ordinary sense. He meant to imply that the temperature, pressure, and concentration of an explosive mixture before, during and after combustion, in conditions of turbulence, high turbulence, or little or no turbulence, were considered in this paper.

The result of these papers and of the discussions which followed upon them was bound to resolve itself into a synthesis of ideas, which would clear up the extraordinarily complicated phenomena which went on in the combustion process. He hoped there would be a good discussion that evening, and that any number of questions would be directed to Mr. Alcock.

Mr. J. S. Jackson, who was called upon to open the discussion, said that the invitation had taken him entirely by surprise. The

subject was one upon which he hardly felt himself competent to speak, but it was obvious that the experiments described opened up many new possibilities. The apparatus was extraordinarily ingenious, and the experiments really gave a very clear picture of what was happening in the combustion space of the I.C. Engine. He had hoped that the author might be able to indicate the possibility of connecting the rate of flame propagation with the complicated phenomena of knocking and detonation which were so very obscure.

As to comments on the paper itself, he was afraid he had very few to offer, but it would be interesting to know whether any striking differences were observed with variations of fuel. The experiments described were obviously of a preliminary nature and it would be of interest to learn where the author thought that this investigation was going to lead. What hopes were entertained of pursuing the matter and what was the next step going to be ?

Before sitting down he desired to add his own word of compliment to that already spoken by the President.

Mr. R. Stansfield said that the observation that the velocity with which the flame spread from the nucleus was nearly proportional to the rate of pressure rise, and not dependent in its early stages on the strength of mixture surrounding it, was of interest, since this behaviour agreed with that recorded in the bomb experiments of Maxwell and Wheeler, with and without turbulence. The general agreement between these two lines of investigation was remarkably good as far as they could be co-ordinated, allowing for the necessary difference in absolute values between the high rates of flame velocity and pressure rise in the engine, and the relatively low rates in the bomb experiments. It would be interesting to hear whether Mr. Alcock had any information regarding flame travel when detonation occurred, and also whether he had studied the effects of change of fuel, and in particular the effect following the addition of dope, such as lead tetraethyl, on the rate of flame travel.

A value of approximately 0·14 in. was given in Fig. 3 as the critical point for clearance above the piston. Below 0·14 clearance the H.U.C.R. of the poorest suitable fuel could be dropped. He desired to know a little more about these characteristics with different dimensions of cylinder.

In connection with the theory that detonation was due to auto-ignition of the compressed unburned products ahead of the flame, had such auto-ignition been observed in any tests similar to those described, but in which detonation was present ? There was indirect evidence from tests on anti-knock values with certain pure hydrocarbons which suggested that auto-ignition was only

occasionally the cause of the noise referred to as detonation, and that in many cases it must be due to a shock effect initiated in the products of combustion after the flame had passed through, and must be dependent to a certain extent on the acoustic properties of the combustion chamber. That, also, was in a line with the bomb experiments of Maxwell and Wheeler.

Mr. A. A. Ashworth desired to refer also to Fig. 3, from which it appeared that with the smallest head clearance there was actually an H.U.C.R. obtained of 7·5. Apparently that same head was not the one used in the experiments where a compression ratio of about 5·5, he thought, was employed. If an H.U.C.R. of 7·5 was obtained, it would be interesting to know whether the fuel used was of a special anti-knock type, because it would be almost impossible to obtain such an H.U.C.R. with fuel unless of special benefit in that head. If, then, also with No. 2 cylinder head, one could obtain an H.U.C.R. of 7·5, surely that would have been a compression ratio for use in the experiments to give the maximum power.

Mr. E. R. Redgrove said that the paper appealed to him as a piece of most interesting work, and that the way in which it had been presented was worthy of the highest praise. In view of the accurate and scientific nature of the work carried out by the author, he felt that all steps must have been taken to avoid extraneous, contaminating material, but he would like to ask Mr. Alcock what precautions were taken to purify the air which was mixed with the fuel for making the explosive mixture. The speaker's own work on the decomposition of lubricating oils and the friction of such oils had shown that the admission of the minutest traces of foreign materials, such as water vapour, sulphur gases or dust, had a profound effect upon the results obtained, and he could quite imagine that ordinary dust would have a distinct effect upon the rate of propagation of flame.

Mr. D. S. Paul said that, apart from alluding to the remarkable ingenuity of the apparatus and experiments, he would like to say that he was rather in agreement with Mr. Stansfield and Mr. Jackson in that this work opened up quite a large field of investigation into the problem of detonation.

It was obvious from the results given in the paper that the rate of flame propagation could be accurately determined by this method. The interval of time in terms of degrees of crankshaft movement from ignition until the appearance of luminosity at observation hole No. 6, being that most remote from the point of ignition, could be determined with non-knocking and then with knocking fuel. If it was shorter with the latter, it would be strong

evidence of the correctness of the commonly accepted theory of detonation. This having been done, an investigation could then be made unto the effects of different anti-knock bodies. Recent work seemed to indicate that fuels equivalent in anti-knock value at one temperature and at one engine speed might disagree violently if tested under different conditions. He recently encountered a mixture of something like 70 per cent. Mid-Continent gasoline and 30 per cent. benzol, which was equivalent in knock rating at 212° F. to a straight-run Californian stock, and when the cooling medium was altered and a temperature of 350° F. was obtained, then much more than 30 per cent. of benzol was required to be added. The same thing seemed to apply to the effect of lead tetraethyl. He thought that with a little modification this stroboscopic method might actually solve the whole problem and throw some light on a subject which was at present very difficult. The paper was chiefly concerned with elaborating the effect of turbulence. He thought that the benefit given to the chemist in exposing the mechanism of the combustion would really be very far-reaching in the future.

Mr. J. F. Alcock, in replying on the discussion, thanked the speakers for their remarks about the paper and the work which had been carried out. Several speakers had asked the question as to the continuation of these tests. They were being continued, and what had been brought forward that evening was only the beginning of a very long series of tests. These tests had mainly been aimed so far at the development of improved forms of combustion-chamber, that is, on the engine side of the research rather than on the question of fuels or of detonation. He expected these other questions would be dealt with later, but at present relatively little had been done. Research had been directed mainly to improving engine performance.

Another question which had been asked by the President and Mr. Jackson and other speakers was as to the effect of detonation on the flame. No effect could be seen in the earlier part of the flame spread, but in the last sight-hole—and he thought sometimes the last two—the light changed in colour very considerably. Normally it was yellowish, the exact shade depending on the strength of the mixture. It became more markedly yellow with rich mixtures. But when an appreciable detonation occurred, the flame at the end of its travel became a very brilliant white. Apparently the phenomenon was very much confined to the last inch or so of travel, and as that was only covered by one sight-hole, one could not get much information as to the effect of detonation on the actual velocity. This was a matter which would have to be looked into later, but not much research had been done upon it hitherto.

Mr. Stansfield had asked whether the critical value of clearance varied with cylinder size. The matter had not been investigated over a very great range of cylinder size, but it certainly appeared not to vary very much. He thought he would like to leave it to Mr. Glyde to amplify the answer to that question when he made a written answer to the discussion, but he thought he could say that the variation was relatively slight.

Mr. Stansfield's question as to whether there were any signs of self-ignition ahead of the flame when detonation occurred had been rather answered by what he had already stated, that the detonation occurred in such a limited area that it was not possible, with the apparatus at present existing, to study it very closely. He hoped later that it would be possible to obtain more information on that point.

Mr. Ashworth and others had raised the question as to the nature of the fuel used and as to why a constant compression ratio was employed — in other words, why, with heads such as No. 2, where a high-compression ratio could have been used, it was not in fact used. All the values used were tested in the standard variable compression engine, which had been many times described, and the procedure in this case was that if one wanted to measure the detonating tendency of a head of this kind, it was obviously not very easy to vary the compression ratio, and so what was done was to use a head of one ratio, generally about 5 to 1, and to make tests with different fuel mixtures. Such mixtures were, perhaps, of petrol of very low H.U.C.R. value and benzol, or with another petrol with a higher H.U.C.R. value. Various mixtures were tried until one found a mixture which gave in the test engine the degree of detonation which was taken as standard when making petrol tests in the variable compression engine. That fuel mixture was then tested in the variable compression engine, and the compression ratio found which gave the same degree of detonation in the variable compression engine as had been found in the research engine. Let it be supposed that the research engine had a compression ratio of 5 to 1, and the fuel mixture which just detonated in the head one was testing, detonated in the variable compression engine at 4 to 1, one would express that by saying that the H.U.C.R. which could be used in that engine was 6. That was quite an arbitrary way of doing it, but it gave relatively good values. It had been found, incidentally, that the relative values were given rather better by simple addition than, as one might at first think, by proportion—that is, by saying that a particular head was one ratio above standard, the variable compression engine being taken as standard, rather than by saying that it was 20 per cent. above standard.

Mr. Ashworth had also asked why they did not in these tests increase the compression ratio in order to get the maximum output. The answer to that was that these first tests made with the apparatus were aimed at getting the effect of turbulence. Therefore one wanted to keep all other variables as much as possible the same. It would be better to leave it to a later series of tests to vary the compression ratio.

Mr. Redgrove had asked whether any special steps had been taken to purify the air, and he had given some very interesting data as to the effect of these small impurities on lubrication. The speaker had no idea that the small impurities obtained in the air could make these marked differences. In the cases recorded in the paper no special steps were taken. The effect of water vapour and free sulphur had been examined in the variable compression engine and, although appreciable in large quantities, the proportions found in the air were not enough to make any appreciable difference. He had been asked whether any experiments had been made with regard to the effect of dust on detonation. Under ordinary laboratory conditions one did not get an enormous amount of dust in the engine. It must be remembered that there would be a certain amount of small carbon particles in the combustion chamber left over from the last combustion, and he would have thought that the little more brought in with the induction air would not make much difference, unless, of course, it contained something in the nature of dope, which was not very likely to be the case with ordinary dust.

He thought he had already answered Mr. Paul's first question about the detonation being observed in the last hole. That was where it was always observed. It appeared to be very much localised at the far end of the flame path. He did not think he could give any figures at present with regard to the behaviour of different fuels. A little had been done on this subject, but he had not the data with him, and he thought it would be best to leave that matter to Mr. Glyde to deal with when he made his written answer. All the tests given in the paper were done on the fuel which was described in the text. It was a straight-run petrol.

On the motion of the President, a hearty vote of thanks was accorded to Mr. Glyde for writing the paper and to Mr. Alcock for presenting it.

The meeting then terminated.

Mr. H. S. Glyde, in reply written from hospital, said that there was very little to add to Mr. Alcock's verbatim reply to the discussion.

Questions had been raised as to what further work had been done, what was the effect of detonation, and whether after-burning had been observed through the sight-holes. Most of the research work subsequent to the experiments described has been carried out with a view to investigating the effect on performance of variations in the conditions of combustion and in turbulence as brought about either by changes in the shape of the combustion chamber itself or by alteration of valve size. The effect of head clearance on the degree of detonation has been dealt with more fully in an article in the February issue of the "Automobile Engineer" on "Combustion Chamber Research."

There is as yet nothing to add to what has been said in relation to the observations, described by Mr. Alcock, which had been made during the occurrence of detonation. It should be emphasized that for obvious reasons the velocity of the flame over the short distance at the end of the travel when the detonation flash took place could not be accurately determined with the present disposition of the sight holes.

What changes in the velocity of flame travel accompanied the use of fuels of different characteristics had not at present been investigated.

With regard to different sizes of cylinder, the general evidence from tests on other engines pointed to an agreement with the results contained in this paper, in which it was shown that there was a critical value of head clearance in relation to detonation, in this case approximately 0·14 in. In practice it has been found advisable to use a clearance of rather less than this value, irrespective of the size of cylinder.

In carrying out a long series of tests on a side valve engine, the use of different compression ratios and different fuels would have led to complications in the determination of engine performance when obtaining comparable results from various combustion chambers. The conditions of combustion—e.g., surface-volume ratio and combustion-chamber shape—would have been upset by alteration of compression ratio. It was therefore decided to standardise both the compression ratio and the fuel. As explained in the spoken reply, in order to obtain a basis of comparison between various combustion chambers in respect of their tendency to detonate the method of fuel mixtures of known H.U.C.R., determined in the variable compression engine, was employed.

No tests on flame velocity using fuels with such substances as lead tetraethyl have, as yet, been carried out, but this would appear to be a very promising line of research.

He hoped at a later date to be able to amplify the reply to the discussion.

The Total Heat and Specific Heat of a Series of Fractions of Petroleum Oil, and their Relation to other Properties.*

By H. R. Lang, Ph.D., F.Inst.P., Research Fellow, Institution of Petroleum Technologists, R. Jessel, A.R.C.S., D.I.C., B.Sc., Demonstrator, Imperial College of Science, and A. H. Steed, A.R.C.S., D.I.C., B.Sc.

Part I.—On the General Scheme of the Research, and the Selection and Preparation of the Samples.

By H. R. Lang, Ph.D., F.Inst.P.

1. *The General Scheme of the Research.*—The object of the research is to contribute towards the collection of systematic and reliable data on the thermodynamic properties of petroleum oils and products, in an attempt to find a rational system of equations that will represent their physical properties in both liquid and vapour states. A set of such equations is available for the properties of steam and water and a few other simple substances. It is clear that the matter will be more difficult in the case of petroleums owing to their complex nature, and it is doubtful if it will ever be possible to completely analyse any ordinary oil into its separate types of molecules. So that even if the physical properties of all molecules were found, as well as the laws for deducing the resultant properties of mixtures of such molecules, the problem would still be unsolved. The alternative then, is to divide and subdivide the oils, and products into groups, and to study the properties of these groups, in the attempt to obtain some order out of the chaos.

The general scheme of the present work has already been given in an earlier paper.[1] With the co-operation of the Institution of Petroleum Technologists and of the oil companies, a systematic study has been commenced, and the following papers represent a first series of results. Much time and thought have been expended in trying to avoid the further accumulation of sporadic data, an accumulation which has been recently surveyed by Cragoe[2], and the result of his work shows very plainly how much a well-organised systematic study is needed. The physical side of this work is following along lines suggested by the late Professor Callendar, and used by him for water and steam.

2. *The Selection of Samples.*—The final selection of the samples was left to those members of the Institution of Petroleum Technologists who were in a position to supply them, and samples of some representative types have been obtained.

It was originally proposed that the crudes should be fractionated by the various refineries according to some definite scheme; and that the separate fractions, and residues at each stage should then

*Paper received August 1st, 1930.

be studied. Difficulties at once arose owing to the use of different types of still, and the different technique used. Despite many kind offers of assistance, it soon became apparent that, at any rate in the early stages of the work, the only way to obtain fractions that could be considered comparable, was to prepare them all in the same still, with distillation conditions as near the same as possible. A search was therefore made for a suitable still, which could be accurately controlled. A one gallon still, in the oil technology department of the college, was put at my disposal by Mr. A. Wolf ; this was the one used for topping the crude oils.[1] After making some modifications, it was tested with a 50 per cent.–50 per cent. mixture of toluene and benzene and found satisfactory for the work. If the fractions were to be prepared direct from the crude, a much larger capacity still would be needed (about 50 gallons), and renewed difficulties would arise of exact control and close fractionation. The original scheme of preparation from the crudes had therefore to be abandoned, and after consideration of numerous proposals, ranging from a study of the pure hydrocarbons to the commercially prepared rough fractions, a scheme was drawn up which proved satisfactory to all concerned. Fractions were to be prepared from the straight run benzines and kerosines, and these were to be blended in such a way that a good approximation would be made to the fractions that would have been obtained by perfect fractionation of the crude, a process that seems to be insuperably difficult. The straight-run benzines and kerosines were therefore obtained from the refineries and fractionated into 25° C. cuts and blended in the manner described below.

Standard A.S.T.M. flask distillation tests were carried out on a number of the fractions made, and it was found that on the average 97 per cent. boiled within the range of the cut made.

3. *Scheme of Blending.*—It is supposed that on distillation the crude yields—

(a) per cent. benzine by volume ;
(b) per cent. kerosine by volume ;
(c) per cent. gas oil by volume.

These figures being the actual yields at the refinery, and not the results of laboratory tests, with different fractionation. If on re-distilling these straight-run refinery cuts, the following figures are obtained for the 25° C. cuts, between 75° C. and 200° C. (vapour temperatures) :—

TABLE I.

Percentages by Volume.

Fraction No. ..	1	2	3	4	5
Boiling range ° C.	75–100	100–125	125–150	150–175	175–200
From benzine	a_1	a_2	a_3	a_4	a_5
From kerosine	b_1	b_2	b_3	b_4	b_5
From gas oil	c_1	c_2	c_3	c_4	c_5

then, initially in the crude, there was present :—

$aa_1+bb_1+cc_1$ per cent. by volume of fraction No. 1,

$aa_2+bb_2+cc_2$ „ „ „ No. 2, etc.

In the case of the present series, from Miri crude, the values of c_1 to c_5 were zero, *i.e.*, the initial point of the gas oil was above 200° C. and only the benzine and kerosine had to be re-re-distilled.

Then bb_n/aa_n cubic cms. of the kerosine cut was blended with each cubic cm. of the corresponding benzine cut, where n is the number of the cut.

Six batches of the stright-run Miri benzine, and four of the straight-run kerosine were distilled, and the average figures obtained are given in Table II.

TABLE II.

Percentages by Volume.

Fraction No.	1	2	3	4	5
Boiling range ° C.	75–100	100–125	125–150	150–175	175–200
From benzine	22·0	31·0	20·0	15·0	8·5
From kerosine	0·9	3·7	7·5	20·0	27·7

The residue from the benzine above 175° C. was put with fraction No. 5, since the final boiling point was 200° C.

The initial boiling point (vapour temperature at the top of the column) was 45° C. for the benzine and 97° C. for the kerosine.

4. *Analyses of Samples.*—The following particulars of these samples, and of the crude, were kindly supplied by Mr. J. Kewley.

Miri Crude Oil.

1. Origin—Miri in British Borneo.

2. The percentages of products obtained from this oil in the refinery are as follows :—

17 per cent. of benzine by weight,
10 per cent. of kerosine by weight,
10 per cent. of solar oil by weight,
62 per cent. of residue by weight,

the qualities of the benzine and kerosine obtained correspond to the analyses given below, dealing with these products.

3. Specific gravity at 60° F.=0·887.

4. Distillation.

I.B.P. 114° C.

Percentage to 125° C.	2·5	per cent.
„ „ 150° C.	9·5	„
„ „ 200° C.	23·0	„
„ „ 250° C.	41·0	„
„ „ 300° C.	65·0	„

Viscosity Engler at 30° C.=1·32.

Miri Benzine.

1. Specific gravity at 60° F.=0·7775.

2. Distillation.

I.B.P. 81° C.

10 per cent. distilling at	..	..	101·5° C.
20 " "	..	..	107·0° C.
30 " "	..	..	111·5° C.
40 " "	..	..	116·0° C.
50 " "	..	..	122·0° C.
60 " "	..	..	129·0° C.
70 " "	..	..	138·0° C.
80 " "	..	..	150·0° C.
90 " "	..	..	167·0° C.

F.B.P. 200° C.

3. Aromatic content= 3·3 per cent. by weight.
Napthene content=92·2 per cent. by weight.
Paraffin content (by difference)=4·5 per cent. by weight.
4. Sulphur content=0·02 per cent.

Miri Kerosine.

1. Specific gravity at 60° F.=0·825.
2. Distillation.

I.B.P. 140° C.

10 per cent. distilling at	..	..	163° C.
20 " "	..	..	172° C.
30 " "	..	..	179° C.
40 " "	..	..	188° C.
50 " "	..	..	195° C.
60 " "	..	..	201° C.
70 " "	..	..	208° C.
80 " "	..	..	216° C.
90 " "	..	..	231° C.

F.B.P. 260° C.

5. *Acknowledgments.*—The author has had the great advantage of the continual advice and encouragement of both Mr. A. A. Ashworth and Mr. A. Wolf, in the oil technology department of the college, during this part of the work. The distillations were carried out with the assistance of Mr. Jessel and of some of the oil technology students. In addition, on several occasions, the author has been privileged to receive the valuable advice of the members of the Research Committee of the Institution of Petroleum Technologists and of some of their assistants. To all of these the author wishes to express his gratitude, as well as to the oil companies who kindly supplied the samples.

References.

[1] Lang and Jessel, *J. Inst. Petr. Techn.*, 1930, **16**, 476.
[2] Cragoe, Misc. Publications, Bureau of Standards, No. 97 (1929).

Part II.—The Temperature Variation between 0° C. and 100° C. of the Specific Heat of the Fractions.

By R. Jessel, A.R.C.S., D.I.C., B.Sc.

1. *Introduction.*—This part of the paper describes experiments carried out by the continuous flow electric method between 0° C. and 100° C. on the 25° C. cuts prepared from Miri oil, as described

in Part I. The total heats obtained by integrating the results were used as a basis for the calculation of total heats at high temperatures (Part III.). The method and apparatus have been described in a previous paper[1]. and all that need be added is a note of some additions and improvements that were necessary when dealing with light petroleum oils.

2. *Additions and Improvements to the Apparatus.*—The large flat tank described in the previous paper was replaced by an overflow device which allowed much smaller quantities of liquid to be used. This is a great advantage as it greatly reduces the amount of distillation necessary to prepare a sample.

The take-off pipe from the lower reservoir A (Fig. 1) to the pump P was at the bottom and allowed all the oil to be used, while the drain-cock F allowed the tank to be emptied with ease. The oil was pumped up continuously into the brass overflow chamber B, where a very wide tube passed up through the bottom and carried the excess liquid back to the reservoir at G. The upper end of the overflow chamber was closed with a cork pierced with a small hole to reduce evaporation to a minimum, at the same time keeping the chamber at atmospheric pressure.

Such a large quantity of dissolved air was released in the apparatus from these light oils at the higher temperatures that it was impossible to obtain any steady readings. A de-ærating apparatus (Fig. 1) was introduced in order to ensure that only air-free oil was supplied to the overflow and consequently only air-free oil entered the flow apparatus.

The de-ærating apparatus consisted of a heater H in which the oil was raised to within a few degrees of its initial boiling point and the air released, and a cooler K in which it was reduced to room temperature before entering the pump. In the heater the oil was sucked through the small annular space between two co-axial cylinders, where it was thoroughly shaken by a spiral of jack chain, and the air was allowed to separate in the space E at the end. The air port was connected to a long, wide cylindrical glass tube D, the upper end of which was narrowed down and led back into the top of the reservoir A. The heater was placed on the suction side of the pump well below the level of the reservoir, which was not allowed to empty, so that there was always liquid in D as the pressure was only slightly below atmospheric. The temperature of the oil was measured with a thermo-couple T calibrated *in situ* against a mercury thermometer immersed in the heater. The power was supplied by a heating coil wound on the outside of the heater, and the oil was maintained at the required temperature by adjusting the current in this coil and by changing the speed of

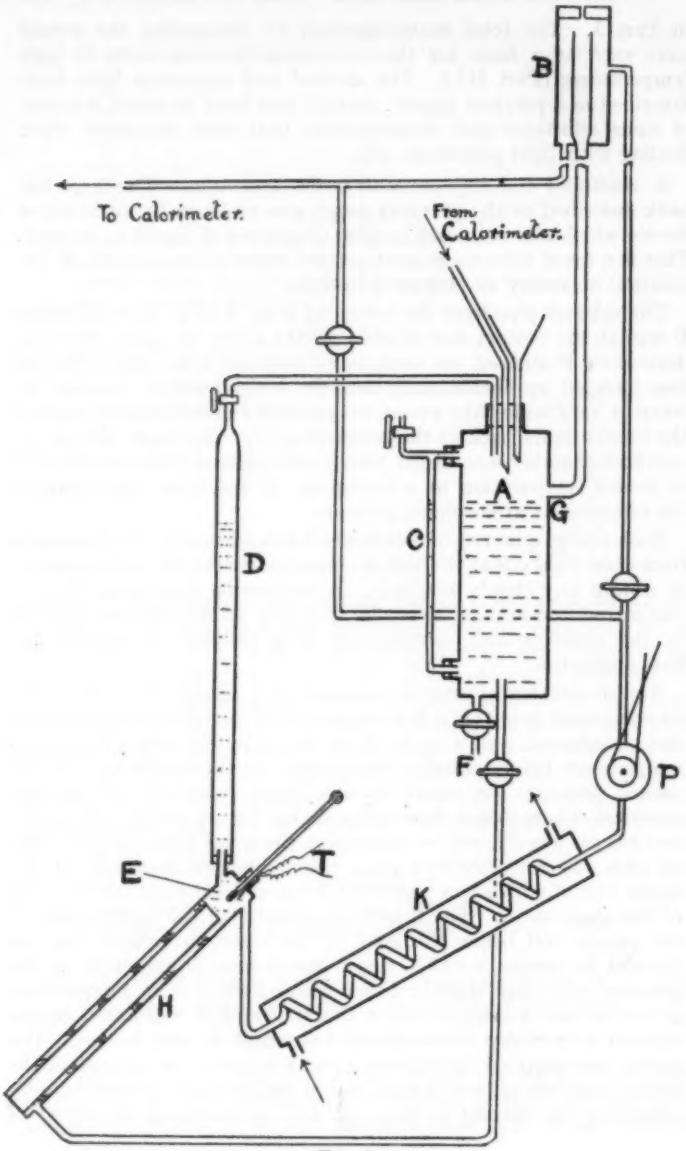

FIG. 1.
THE DE-AERATING APPARATUS AND OVERFLOW DEVICE.

pumping. The cooler K consisted of a spiral of metal tubing contained in a brass cylinder through which a stream of water was passing.

All the metal taps in the apparatus were changed for cork-seated petrol taps, which were more satisfactory for these light fractions. The measuring instruments were arranged so that all the readings could be taken by one observer.

3. *The Results.*—The following table sets forth the results obtained. The specific gravities given are the mean of the values at the end of each experiment and for a given fraction they showed only a random variation of less than 0·001, which was considered sufficiently constant. The values were reduced to those at 60° F. by temperature coefficients derived by a series of determinations of the thermal expansions of these fractions (Part V.). The value of the mechanical equivalent was taken as 4·180 joules per calorie, so that the results are in terms of the 20° C. calorie. All temperatures have been reduced to the gas scale.

TABLE III.

Fraction and boiling range.	Specific gravity 60° F./60° F.	Specific heat cals./grm. ° C.	Mean temperature ° C.
No. 1 (75° C.–100° C.)	0·7583	0·4956	56·1
		0·5124	70·3
		0·5107	70·3
		0·4999	64·0
		0·5004	64·0
		0·4686	34·6
		0·4408	3·9
		0·4972	57·4
		0·4800	43·6
No. 2 (100° C.–125° C.)	0·7680	0·4560	25·6
		0·4906	59·4
		0·5185	82·2
		0·5184	82·2
		0·5258	91·3
		0·4363	4·6
		0·4354	4·6
No. 3 (125° C.–150° C.)	0·7862	0·4536	23·3
		0·4835	52·6
		0·4355	4·7
		0·5193	88·1
No. 4 (150° C.–175° C.)	0·8070	0·4470	19·3
		0·4786	50·9
		0·5119	82·4
		0·4342	4·6
No. 5 (175° C.–200° C.)	0·8295	0·4638	42·3
		0·4871	66·2
		0·4880	66·3
		0·4458	23·7
		0·4457	23·6
		0·5202	98·3

These results have been plotted in Figs. 2, 3 and 4.

The variation of specific heat with temperature of the fractions Nos. 3, 4 and 5, has been taken as linear with a positive coefficient of 0·001 per ° C. Although this is sufficiently true for all practical purposes, it is to be noted that the values definitely indicate a slight curvature, denoting that a very small term involving the second power of t is necessary to complete the equation.

The equations taken to represent the temperature variation of the specific heat of these fractions are :—

No. 3. $s=0{\cdot}4305+0{\cdot}001t$.
No. 4. $s=0{\cdot}4282+0{\cdot}001t$.
No. 5. $s=0{\cdot}4217+0{\cdot}001t$.

The results obtained with fraction No. 2 indicated that between 0° C. and 70° C. the temperature variation was again linear and of the same slope, being represented by an equation :—

No. 2. $s=0{\cdot}4315+0{\cdot}001t$.

The mean value at 82° C.—two values agreeing to 1 part in 5,000—was found to be considerably higher than would be expected from this equation. At this temperature, which is only 18° C. below the initial boiling point of the fraction, there is a probability of a number of vapour molecules in solution and these would cause a higher specific heat. The value at 91° C., however, although much higher than the linear formula, was lower than an extrapolation from the other points. This effect, that near the boiling point of the oil the results would indicate a diminution in the slope of the specific heat curve, had already been noted with the crude oils.[2] It was unfortunate that owing to losses by evaporation and a series of minor accidents the quantity of this oil ran so low that it was impossible with this fraction to investigate this point further.

The specific heat-temperature curve for fraction No. 1 was traced right up to its initial boiling point and showed the same peculiar shape. A rise in the curve towards 0° C. was observed. This no doubt is due to the presence of benzene (C_6H_6), which freezes at about 5° C. The presence of solid molecules in solution therefore is highly probable. It is to be noted that a very small amount of this substance in the fraction would give the observed rise in specific heat. From 30° C. to about 60° C. the curve rises more rapidly than the linear formula of the other fractions ; at 60° C. the slope becomes less, but about 65° C. it again increases more rapidly than at first. A suggested explanation of this peculiar variation is given in Part V. of this paper.

References.

[1] Lang and Jessel, *J. Inst. Petr. Techn.*, 1930, **16**, 476.
[2] *Loc. cit.*, p. 495.

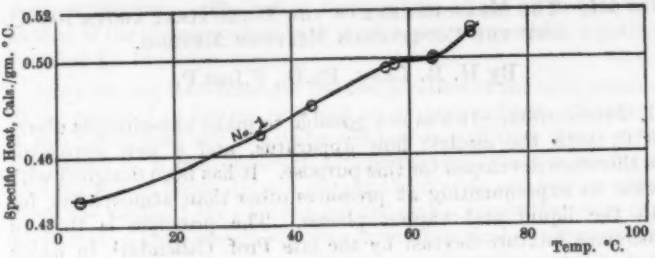

FIG. 2.

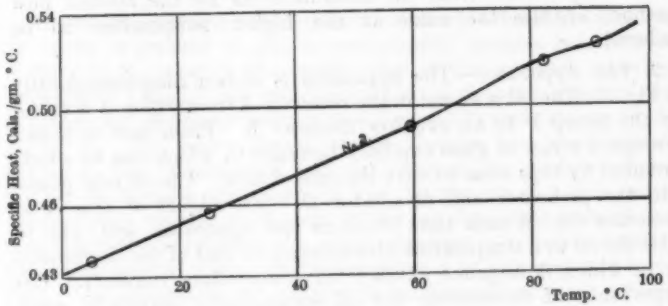

FIG. 3.

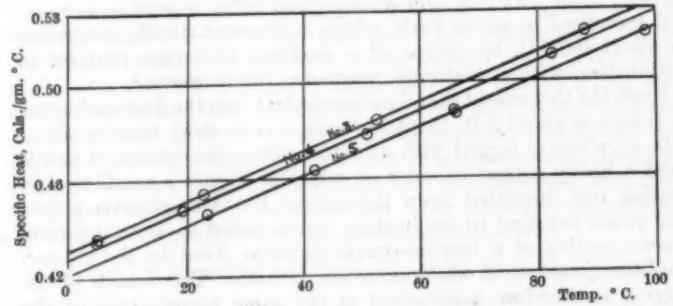

FIG. 4.

SPECIFIC HEAT—TEMPERATURE CURVES.

PART III.—THE MEASUREMENT OF THE TOTAL HEAT ABOVE 100° C. BY THE CONTINUOUS MIXTURE METHOD.

By H. R. LANG, Ph.D., F.Inst.P.

1. *Introduction.*—It was not possible to make experiments above 100° C. with the electric flow apparatus, and a new apparatus was therefore developed for this purpose. It has been designed with a view to experimenting at pressures other than atmospheric, for both the liquid and vapour phases. The principle is that of continuous mixture devised by the late Prof. Callendar[1], in which direct measurements are made of the drop of total heat of a stream of oil, by cooling it with a stream of water and measuring the heat so extracted. The knowledge of the total heat of the oil at the lower temperature, from the measurements by the electric flow method, enables the value at the higher temperature to be deduced.

2. *The Apparatus.*—The apparatus is shown diagrammatically in Fig. 5. The oil is stored in the reservoir A from which it is raised by the pump P to an overflow chamber B. From here it passes through a series of glass capillary throttles C, which can be short-circuited by taps so as to vary the rate of flow. The oil now passes into the preheater and de-aerater D. The object of this is to de-aerate the oil each time it enters the apparatus, and also to raise the oil to a temperature almost equal to that of the thermostat F, in which it acquires exactly the temperature required. The importance of de-aerating the oil continuously, especially when experimenting near the boiling point, cannot be too strongly emphasised. During an experiment the air port E is left open, so that the air escapes as fast as it is released. The oil then passes through some 25 ft. of thin-walled brass tube, wound in a spiral and immersed in an oil bath, which is thermostatically controlled to about 0·03° C. by means of a modified Callendar recorder in conjunction with a platinum resistance thermometer.[2]

From the thermostat the oil passes straight into the heat exchanger H (which is about 3 ft. long), through a very short German silver tube G, which is lagged with asbestos. Over the outside of this is fixed a heavy copper cylinder on which is wound a small electric heating coil, insulated from the copper by thin asbestos paper. The power supplied to the heating coil is varied so as to maintain a zero reading of a thermo-couple junction fixed to the copper, the other junction of which is in the oil bath. The outside of the lagging is therefore maintained at the same temperature as the inside, and hence the heat loss from this connecting pipe reduced almost to zero. After trying many other methods this was found

very satisfactory. The inflow temperature of the oil is thus taken as that of the thermostat oil bath itself, a procedure which is perfectly justified by the experiments.

After leaving the exchanger the temperature of the oil is measured in the pocket I to the top of which an air trap is fixed. In practice it was found that the de-aerater worked so well that if any air did get passed it, it had apparently dissolved again before leaving the exchanger, and hence did not restrict the flow to any serious extent. From the pocket I the oil flows out through a special two-way tap J made from a cork-seated two-way petrol tap, and so arranged that the flow is never stopped in switching over from the one side to the other. The oil runs back to the reservoir, from the other side, and from the other it can be collected in a tared flask, in order to measure the rate of flow.

The cooling water is supplied from an overflow head K which can be raised or lowered to give a continuously variable rate of flow. A filter Q is placed in the supply pipe to the overflow chamber. From this "head" the external jacket of the exchanger is also supplied, and the same water is used to cool the main stream in the cooler N. The main stream passes through the thermometer pocket L, the exchanger H and out through the doubly-jacketed pocket M through the cooler N and on the jet O. This jet is mechanically coupled to the arm of the tap J, so that both oil and water streams are switched over simultaneously. In the one position the water runs to waste, and in the other it is collected in a tared flask. All openings to the atmosphere, such as air ports, are reduced to the smallest possible size to avoid evaporation.

The thermometer pockets were of the type described by Callendar.[1]

3. *Thermometry.*—Four platinum resistance thermometers were specially made for the work, and were used differentially. It is doubtful if sufficiently accurate measurements could have been made with any other form of thermometer; besides giving the greatest quickness and facility of reading, such errors as stem exposure, shift of zero, or stray thermo-electric effects, are all avoided. The difference in temperature of any pair is read directly, and not first one and then the other and the difference deduced, as is often done. The thermometers were calibrated on several occasions in the usual way, in ice, steam and sulphur.

4. *Outline of Theory of the Method, and the Correction for Heat Loss.*—Let

H_1 and H_2 be the total heat of the oil in calories per gm. at the temperatures t_1 and t_2 ° C. respectively.

s the mean specific heat of water in cals./gm. °C. between the temperatures t_3 and t_4 °C.
t_3 the inflow temperature of the water.
t_4 the outflow temperature of the water.
$d\theta=(t_4-t_3)$.
m the rate of flow of the oil in gms./sec.
M the rate of flow of the water in gms./sec.

Then the energy equation per second is—

$$(H_1-H_2)\,m=sMd\theta+\text{heat loss} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The greater part of the heat loss is from the water circuit, and as this is jacketed with water at the same temperature as the inflowing water to the exchanger, this loss is directly proportional to the rise $d\theta$. An investigation of the other small terms, which are of the order of 10 per cent. of the heat loss, or about 1 part in 1000 of the heat exchange, showed that a good approximation could be made by assuming them also proportional to $d\theta$, hence we may write—

$$(H_1-H_2)\,m=sMd\theta+zd\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where z is a constant independent of the flow. The values of m and M are chosen to give almost the same value of $d\theta$ in any one experiment.

5. *Test of the Theory.*—The equation (2) was tested experimentally, with a fourfold change of flow, using water in both flow circuits ; these experiments gave values within less than 1 part in 5000 of the total heat of water, found by Callendar in his classical researches. It was found that z was quite independent of the rate of flow. The theory was further subjected to a severe test in the case of the experiments on oils, and found to hold to a high order of accuracy.

Equation (2) may be written—

$$H_1=H_2+sd\theta M/m+zd\theta/m \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\text{or } H_1=A+zd\theta/m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where $A=H_2+sd\theta M/m$,

and is the total heat uncorrected for heat loss.

Now since H_1, the total heat of the oil at the temperature t_1, is a constant in any one experiment, a test of the equation is provided by plotting the values of A against $d\theta/m$. As the heat loss is small, the value of A does not change very much from flow to flow, and hence a very open scale can be used for the ordinate. It was found that the points in any set of flows (an experiment) were co-linear to an accuracy even better than the estimated experimental error.

The actual value of the heat loss per degree rise (z) is dependent upon a large number of factors, some positive and some negative. All these were investigated, but a full discussion of this will not here be given, as the only essential is that z should be independent

of the values of m and M, and this was amply demonstrated by the experiments themselves. Further, it must be remembered that z is actually measured in each experiment, using the same value of $d\theta$ for all the flows of that experiment, and therefore the various factors on which it depends are the same throughout the experiment.

6. *Method of Reduction of Results.*—The rise in temperature of the water was measured, first without the oil flowing ("cold" readings) and then with the oil flowing ("hot" readings). The value of $d\theta$ was calculated from the difference of these "cold" and "hot" readings, and reduced to the gas scale in precisely the same way as for the experiments by the electric flow method (c.f. Barnes [3] and Lang [4]). In this way many small errors, such as loss of heat by conduction, were eliminated.

The temperatures t_1 and t_2 were also reduced to the gas scale, and the value of H_2 calculated from the integrated equation for the variation of the specific heat with temperature over this range, as found by the electric flow method (Part II.).

The specific heat of water s has been taken as unity in all cases.

The value of "A" was next calculated, and when a "run" had been repeated the average taken. The value of the total heat H_1 is given by—

$$H_1=(A_1m_1/d\theta_1—A_2m_2/d\theta_2)/(m_1/d\theta_1—m_2/d\theta_2) \quad \ldots\ldots (5)$$

and the heat loss per degree rise is given by—

$$z=(H_1—A_1)\,m_1/d\theta_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

In cases when three flows were taken the middle one was calculated from equation (4) by substituting the value of z found from the other two. The two values of H_1 found in this way agreed in general to about 1 part in 600.

An abridged set of observations is appended, which shows the magnitude of the various quantities to be measured, and the agreement between "runs."

TABLE IV.

Miri fraction No. 4. Total heat at $t_1=131{\cdot}55°$ C.

° C.			gms./sec.			Cals./gm.		
t_2	t_1	$d\theta$	m	M	H_2	A	H_1	z
18·50	17·98	7·703	0·7064	4·858	8·092	61·067		
18·50	17·98	7·691	0·7031	4·852	8·092	61·166		
22·12	17·84	7·904	2·0432	13·921	9·715	63·568	64·94	0·351
22·10	17·84	7·886	2·0317	13·885	9·706	63·601		
19·52	17·82	7·789	1·2993	9·077	8·547	62·962		
19·54	17·82	7·747	1·2987	9·132	8·557	63·031	65·09	

Mean value: $H_1=65{\cdot}01$ cals./gm. at $131{\cdot}55°$ C.

The specific gravity was taken after each experiment, in order to keep a check on the loss of any of the lighter constituents of any one fraction. For this purpose a set of N.P.L. certified I.P.T. series A hydrometers was used, and the set was specially purchased

by the I.P.T. for this work. The gravity remained constant throughout the series of experiments.

7. *Summary of Observations and Discussion of Results.*—In Table V. is given a summary of the results obtained with the 25° C. fractions made from Miri benzine and kerosine in the manner described above (Part I.). The values given in the fourth column (H_1 calculated) were obtained by integrating the linear equation fitted to the values of the specific heat of these fractions, found by the electric flow method. The value of the total heat at 0° C. has been chosen as zero in each case.

TABLE V.

Fraction.	Boiling range vap. temp. ° C.	Total heat cals./gm. Obs.	Calc.	% difference.	Temperature ° C.
No. 5 ..	175–200	52·04	52·11	—0·13	109·38
		63·61	63·78	—0·27	130·92
		63·65, 63·56 → 75·93	75·94	—0·01	152·50
No. 4 ..	150–175	53·99	53·83	+0·30	111·30
		64·94, 65·09 → 65·01	64·97	+0·06	131·55
		72·19, 72·08 → 72·13	72·07	+0·08	144·08
No. 3 ..	125–150	55·02, 55·12 → 55·07	55·12	—0·09	113·15
		59·44	59·49	—0·08	121·13
		63·30	63·30	0·00	128·00

It is to be concluded from the close agreement between the observed and calculated values of the total heat, that its variation with temperature for the fractions studied can be well represented by a family of parabolic curves. This means that the specific heat-temperature curves are as near linear as the method can detect. The matter is more fully discussed in Part V. of this paper, with the additional knowledge of the results obtained by Mr. Jessel, using the electric flow apparatus. Unfortunately it was not possible to continue the experiments with fraction No. 5 up to the initial boiling point. For fraction No. 3, the initial boiling point (oil temperature) was found to be about 130° C. The interesting experiment of a measurement of the total heat, above the initial point (vapour temperature) was made, in order to test if these conditions caused a measurable difference from the parobolic equation. Curiously enough, a value was obtained in exact agreement with that calculated.

In order to compare, graphically, the experimental results with the calculated values, the following convenient method has been

adopted. The specific heat equation from the electric flow apparatus is :—

$$s = dH/dt = a + bt \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

therefore by integration the total heat is :—

$$H = at + \tfrac{1}{2}bt^2 \text{ taking } H = 0 \text{ when } t = 0,$$

$$\text{or } H - at = \tfrac{1}{2}bt^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

This last quantity may be termed the " parabolic variation " of the total heat.

In Fig. 6 the quantity (H—at) has been plotted against t^2, the value of H being that found experimentally, and the quantity a is the specific heat at 0° C. obtained from the electric flow experiments. The line drawn represents the equation,

$$0{\cdot}0005t^2 = \tfrac{1}{2}bt^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

since b the temperature coefficient of specific heat has been taken as 0·001 per degree centigrade, for all these fractions (Part II.). This line therefore represents the extrapolation of the electric flow determinations, and it will be seen that the values obtained from these experiments by the mixture method fit this very closely. The minute deviations from the parabolic variation calculated from equation (9) are not sufficient to warrant the inclusion of a cubic term in the total heat equation, although they tend, if anything to lend support to a suspicion of its existence.

12. *Other possible measurements with the apparatus.*—Following along the lines of Callendar's recent application of the method to the determination of the total heat of water and steam up to the critical point,[5] the total heat at any temperature and pressure of both the liquid and vapour states could be found with the present apparatus. This is possible since throttling does not cause any change of total heat, so that by throttling down to atmospheric pressure at the point G (Fig. 5) the total heat is obtained in terms of that atmospheric pressure, and at a temperature below 100° C., where its value is accurately known from the experiments by the other method.

It is hoped, at some future date, to carry out such a series of experiments.

13. *Acknowledgments.*—Most of the apparatus, including the thermometers, was made in the physics workshop, and the satisfactory solution of many of the mechanical difficulties is due to the superintendent, Mr. W. J. Colebrook, and the members of his staff, to whom grateful thanks are due.

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[1] Callendar, *Phil. Trans.*, 1912, A. **212**, 1.
[2] Lang, *Phys. Soc. Proc.*, 1930, **42**, 589
[3] Barnes, *Phil. Trans.*, 1902, A. **199**, 195.
[4] Lang, *Roy. Soc. Proc.*, 1928, A. **118**, 141.
[5] Callendar, " The Howard Lectures," Roy. Soc. Arts., 1926, p. 33.

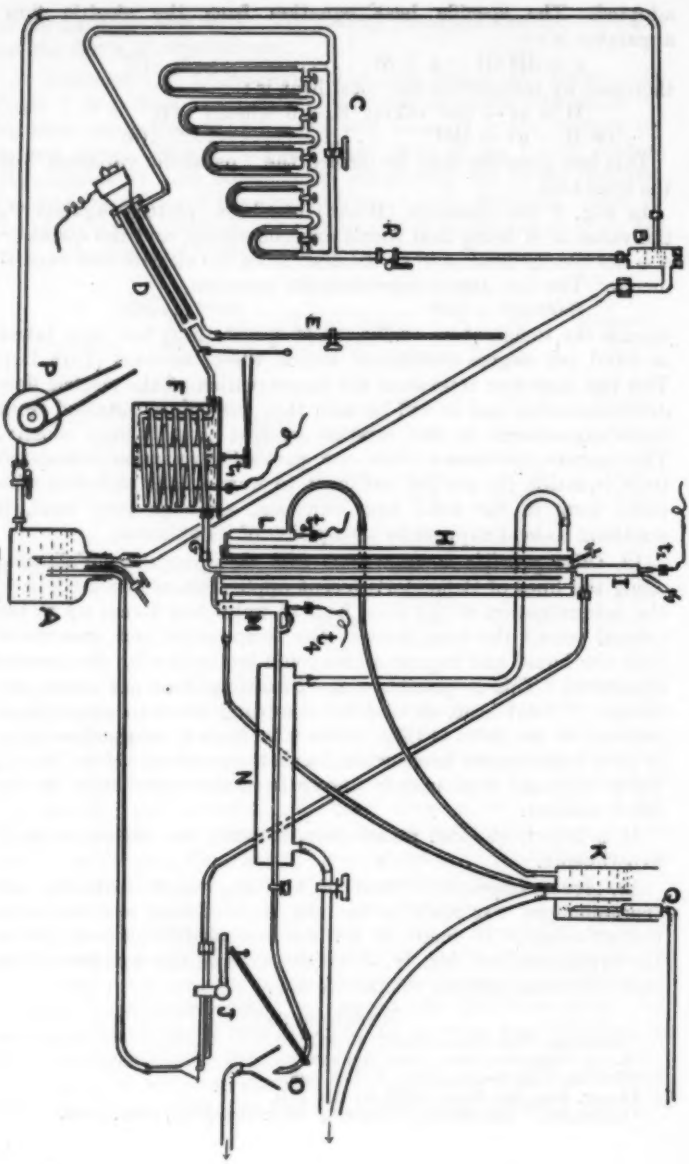

FIG. 5.
FLOW CIRCUITS.

PART IV.—ON THE DETERMINATION OF MEAN MOLECULAR WEIGHTS, AND THEIR RELATION TO OTHER PROPERTIES.

By A. H. STEED, A.R.C.S., D.I.C., B.Sc.

1. *Introduction.*—These experiments were undertaken in order to obtain reliable data on the *mean* molecular weights of close-cut fractions of petroleum oil. The fact that these oil-fractions are complex mixtures of hydrocarbons, makes clear the significance of the term "mean molecular weight." The method employed was that of the depression of the freezing point of a pure solvent.

2. *Experimental Arrangement and Method of Procedure.*—The liquid under investigation was contained in a vertically disposed glass tube, closed by a cork through which passed the thermometer and glass stirrer.

Nitrobenzene was employed as solvent throughout these experiments; and, using very pure naphthalene as solute, the value of the cryoscopic constant K was found by experiment to be a linear function of the depression. The results indicated that at infinite dilution, the value of K was 67·5. The nitrobenzene was "calibrated" by adding successive known amounts of very pure naphthalene to a given mass of nitrobenzene, and plotting the values of the observed depressions of the freezing point against the values of the gram-molecular concentrations of naphthalene per 100 gram-molecules of nitrobenzene. From the observed depression, produced by a known mass of any solute, the molecular concentration was at once given by this curve.

In order to measure accurately the freezing point of the solution, temperature-time curves were obtained by the use of a chromograph and a platinum resistance thermometer in conjunction with a suitable bridge and a sensitive galvanometer, the variation of temperature with time being given by continually noting the changing deflection of the galvanometer. The general nature of the curves is shown in Fig. 7.

OB is the cooling-curve for the solution. Solidification of a portion of the solvent sets in at B, the temperature rises rapidly up to C and then falls slowly along CD. The straight portion CD is extrapolated to A (on the curve OB), which gives the freezing point. Owing to the fact that some of the pure solid solvent has to separate out from the solution to cause the rise of temperature associated with solidification, the concentration of the solution at the point C is greater than that of the original solution. The error due to this effect is proportional to the amount of supercooling, and is eliminated by producing back the straight portion CD to A.[1] In the complete absence of supercooling of the solution

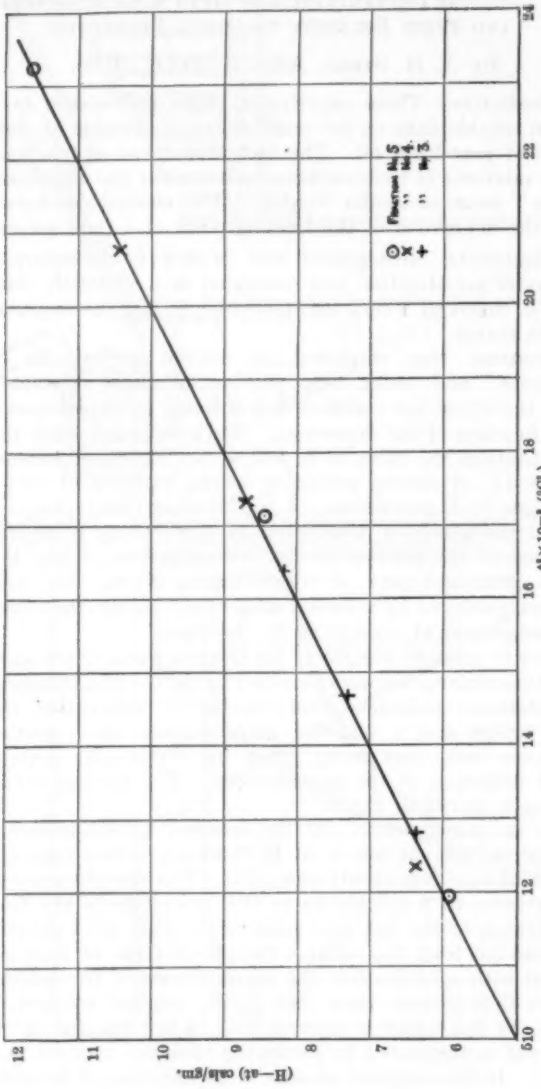

FIG. 6.

EXPERIMENTAL TEST OF EXTRAPOLATED EQUATIONS.

(the realization of which is impracticable), the temperature-time curve would take the path OACD.

Corrections for the effect of thermometric lag were applied to some typical cooling-curves, and were found to have a negligible influence on the results. This might be expected when it is remembered that only the portions OB and CD of the cooling curve serve to determine the freezing point (*cf.* Moulin[1]). The lag corrections merely turn the portion OB slightly to the left, which scarcely alters the ordinate of the point A.

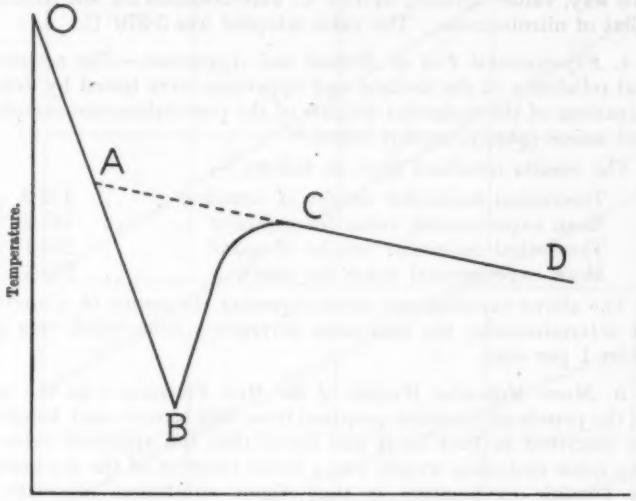

FIG. 7.

TEMPERATURE—TIME CURVE.

3. *The Solvent.*—The advantages of using nitrobenzene as solvent lay in the relatively large value of the cryoscopic constant; and, as it froze at about 5° C., a cooling-bath of ice and water could be used. Apart from other considerations, benzene would have been unsuitable as solvent owing to the presence of small amounts of benzene in the oil-fractions investigated. In some preliminary experiments with nitrobenzene, the values of the freezing point, determined on different occasions, were not consistent; being almost entirely due to the variable amount of water present, arising from the hygroscopic nature of nitrobenzene. This difficulty was overcome by the use of a salt hydrate pair (Na_2SO_4, $0 - 10\,H_2O$), in the presence of which the vapour

pressure of water is constant. According to Roberts and Bury,[2] the hydrate pair keeps the active mass of the water, rather than its concentration, constant; but since the depression depends on the active mass, the difficulty is removed. Sodium sulphate is particularly suitable for this purpose because it is easily purified, is not liable to react with organic substances, and can absorb more water than most other salts. Accordingly, about 2 grams of pure anhydrous sodium sulphate were added to the liquid, whether pure solvent or solution, before determining the freezing point. In this way, values agreeing to 0·01° C. were obtained for the freezing point of nitrobenzene. The value adopted was 5·370° C.

4. *Experimental Test of Method and Apparatus.*—The accuracy and reliability of the method and apparatus were tested by determinations of the molecular weights of the pure substances camphor and anisol (phenyl methyl ether).*

The results obtained were as follows :—

Theoretical molecular weight of camphor ..	152·2
Mean experimental value for camphor	151·2
Theoretical molecular weight of anisol	108·1
Mean experimental value for anisol	108·4

The above experimental values represent the means of a number of determinations, the maximum divergence from which was less than 1 per cent.

5. *Mean Molecular Weights of the Miri Fractions.*—In the case of the petroleum fractions, prepared from Miri benzine and kerosine, as described in Part I., it was found that the apparent value of the mean molecular weight was a linear function of the depression. A possible explanation is that these substances associate in nitrobenzene, and may also form mixed crystals with the solvent; the phenomenon appears to be of regular character on passing from one fraction to another. (Fig. 8.)

The value when the depression was zero (obtained by extrapolation) was taken as the mean molecular weight. This deduction was confirmed by determining the vapour density of fraction No. 1, by Hofmann's method, and the mean molecular weight was found to be within less than 1 per cent. of the figure obtained by the cryoscopic method.

The values obtained were :—

(*a*) Cryoscopic method	88·0
(*b*) Vapour density method	87·3

* The writer is indebted to Prof. J. C. Philip for kindly supplying a high grade sample of anisol.

The agreement between these determinations leaves little doubt that the foregoing interpretation of the curves is correct, and that

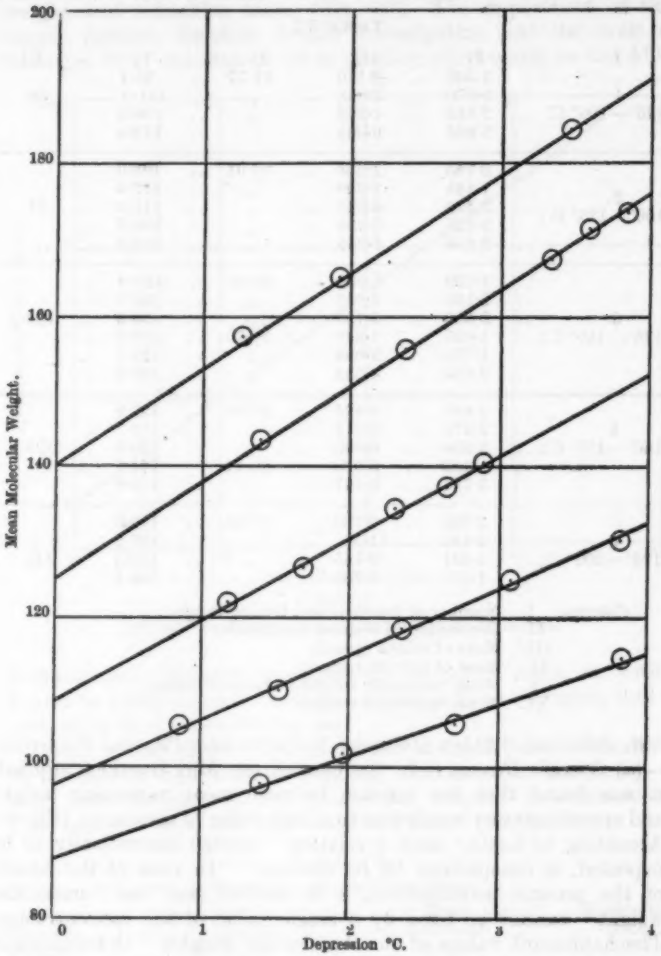

FIG. 8.

MEAN MOLECULAR WEIGHT—DEPRESSION.

the values obtained actually represent the mean or average molecular weight of the various molecules present.

The results obtained for the five fractions investigated are shown in Table VI.

TABLE VI.

I.	II.	III.	IV.	V.	VI.
1 (75°—100° C.)	1·505	2·120	91·77	98·4	88
	2·070	3·038	„	101·9	
	2·815	4·348	„	106·3	
	3·635	6·088	„	113·3	
2. (100°—125° C.)	0·785	1·165	91·91	104·0	97
	1·425	2·300	„	112·8	
	2·375	4·045	„	118·6	
	3·125	5·795	„	126·3	
	3·875	7·745	„	134·4	
3 (125°—150° C.)	1·120	1·950	92·40	120·9	108·5
	2·190	4·195	„	132·7	
	2·580	5·195	„	138·5	
	1·065	1·848	90·70	122·9	
	1·720	3·098	„	127·1	
	2·405	4·638	„	135·9	
4 (150°—175° C.)	2·490	5·425	87·99	157·9	125
	3·370	8·015	„	168·7	
	3·950	9·890	„	175·8	
	1·485	3·020	90·44	144·7	
	3·735	9·467	„	173·9	
5 (175°—200° C.)	3·660	9·730	87·33	189·0	140
	4·135	11·56	„	197·2	
	1·397	3·155	„	158·5	
	1·975	4·705	„	166·1	

Column I. Number of fraction and boiling-range.
II. Depression in degrees centigrade.
III. Mass of solute (gms.).
IV. Mass of solvent (gms.).
V. Mean molecular weight—observed value.
VI. Mean molecular weight.

6. *Relations of Mean Molecular Weight to other Physical Properties.*—(*a*) *Specific Gravity.*—In the case of the Miri fractions studied, it was found that the relation between mean molecular weight and specific gravity was linear to a high order of accuracy. (Fig. 9.) According to Leslie,[3] such a relation "though theoretically to be expected, is conspicuous by its absence." In view of the results of the present investigation, it is evident that the "molecular weight" cannot be fixed by a single value of the concentration. The haphazard values of the "molecular weights" determined in the manner described by Leslie, probably obscured the expected relation with specific gravity.

(*b*) *Refractive Index.*—The refractive indices of the fractions were measured (at 20° C.) by means of an Abbé Refractometer,

and are expressed in terms of the mean wave-length of sodium light. A linear relation was obtained between mean molecular weight and refractive index (Fig. 10). The importance of this simple relation warrants further investigation into its mode of variation from one class of oil to another, particularly as the Abbé

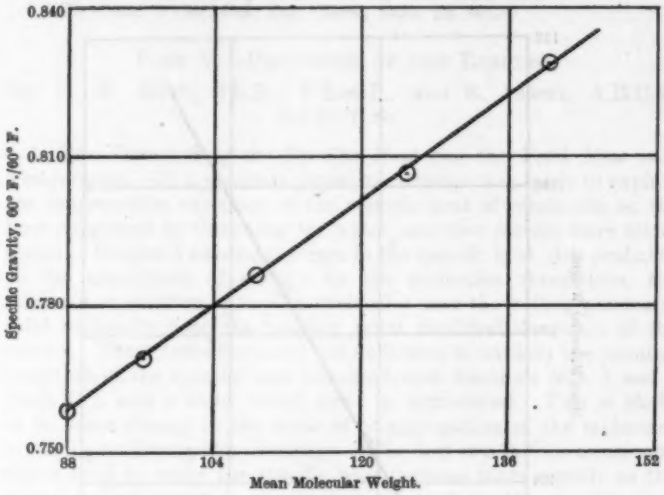

FIG. 9.

SPECIFIC GRAVITY—MOLECULAR WEIGHT RELATION.

Refractometer directly measures the refractive index to within 1 part in 1000, requires only two or three drops of liquid, and is both rapid and convenient in use.

Leslie[3] states that "the 'molecular weights' did not exhibit an agreement with refractive index," and ascribes this defect to some inherent error in the "molecular weight" determinations. This inherent error has been discussed above (Section *a*).

TABLE VII.

SUMMARY OF OBSERVATIONS.

Fraction Number.	Specific Gravity. 60° F./60° F.	Mean Molecular Weight.	Refractive Index. 20° C.
1	0·7583	88	1·418
2	0·7680	97	1·423
3	0·7862	108·5	1·432
4	0·8070	125	1·443
5	0·8295	140	1·455

7. *Comparison with Results of Other Observers.*—In spite of the increasing importance attached to this line of investigation, comparatively little has been done in connection with the mean molecular weights of petroleum products. The few determinations known to the writer were carried out by means of mercurial thermometers, and were stated not to be very reliable.

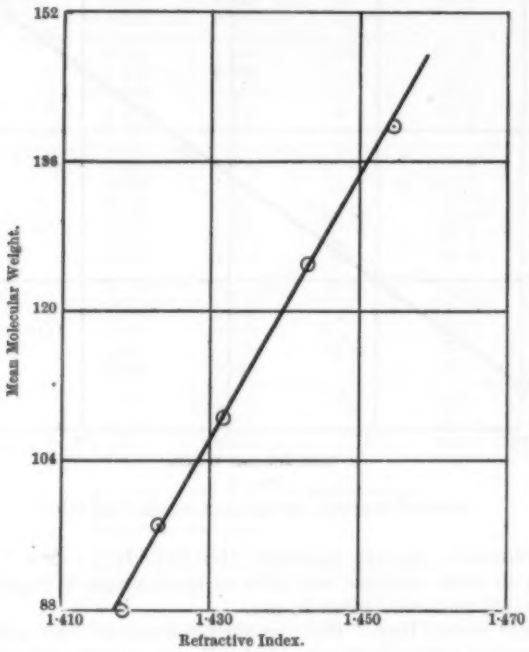

FIG. 10.

MOLECULAR WEIGHT—REFRACTIVE INDEX RELATION.

The mean molecular weights of some heavy petroleum oils have been measured by Wilson and Wylde.[4] These investigators obtained a linear relation between apparent mean molecular weight and depression of freezing point for their lighter fractions, and interpreted their results in a similar way to that given in the present paper.

8. *Acknowledgments.*—This investigation was suggested, in the first instance, by Mr. A. A. Ashworth, and has progressed with the

helpful advice and kindly interest of Dr. H. R. Lang and Dr H. J. T. Ellingham, to all of whom my best thanks are due.

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PART V.—DISCUSSION OF THE RESULTS.

By H. R. LANG, Ph.D., F.Inst.P., and R. JESSEL, A.R.C.S., D.I.C., B.Sc.

1. *The Variation of the Specific Heat and the Total Heat with Temperature.*—In a previous paper[1] an attempt was made to explain the temperature variation of the specific heat of crude oils on the lines suggested by Callendar for water, and two factors were introduced. Besides a natural increase in the specific heat, due probably to the absorption of energy by the molecules themselves, the influence in solution of vapour molecules near the boiling point and solid molecules near the freezing point modified the trace of the curves. These two effects are not sufficient to explain the peculiar variation of the specific heat obtained with fractions Nos. 1 and 2 (Part II.), and a third factor must be introduced. This is likely to be some change in the state of co-aggregation of the molecules involving an absorption of energy. The first two factors mentioned above tend to make the specific heat increase more rapidly as the initial boiling point is approached, so that as the specific heat curve in each case shows a diminution in slope about 10°—15° C. below the initial boiling point, the third factor after being fairly large must fall almost to zero. This would occur when all the molecules have attained their simplest form, as would probably be the case a little before the boiling point. There are three ways in which this change of co-aggregation may take place. The whole change may take place at one definite temperature which would cause a discontinuity in the specific heat curve that would not be observed experimentally, for as ranges of over 6° C. are used, the curve would be considerably flattened. Considering the complicated nature of the substance and the large number of different types of molecule present, it does not seem likely that they would all change state at one and the same temperature, and that this temperature should always be a little before the boiling point. The second possibility is that the change takes place over a small range of temperature during which the absorption of energy increases to a maximum and then falls off to zero, as the majority of the molecules become changed. The change in

the state of co-aggregation may, however, take place over a very wide range of temperature. This means that complicated groups of molecules are broken down successively into less and less complex groups, the absorption of energy steadily increasing and

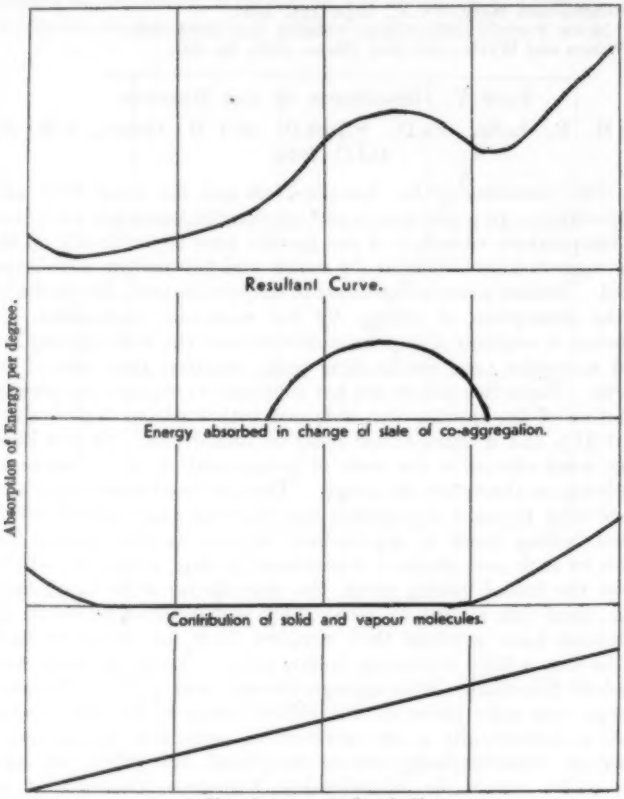
Resultant Curve.
Absorption of Energy per degree.
Energy absorbed in change of state of co-aggregation.
Contribution of solid and vapour molecules.
Natural increase of Specific Heat.
Temperature.

FIG. 11.

DEDUCTION OF SPECIFIC HEAT—TEMPERATURE CURVE.

then falling off to zero when all have attained their simplest form. A suggestion of this type has been made by Antonoff,[2] who concludes that " temperature changes in liquids take place in a discontinuous manner."

In Fig. 11 the three factors are set out in graphical form, the abscissæ representing the temperature, and the ordinates the absorption of energy per degree. The "natural" increase of the specific heat is shown as a line of positive slope, while the curve immediately above represents the energy necessary to form solid and vapour molecules in solution. At the lowest temperature the energy required to "melt" the solid molecules is considerable, but as the temperature rises the number of solid molecules present becomes less, the energy necessary to "melt" them becomes correspondingly less and finally becomes zero. No more energy is absorbed until the boiling point is approached, when vapour molecules begin to form in solution and energy is absorbed in the process. The number of molecules formed increases rapidly as the temperature rises, the energy absorbed increasing proportionately. The third curve, representing the energy used in changing the state of co-aggregation of the molecules, is taken for simplicity as a parabola. By summing the ordinates at corresponding temperatures a curve is obtained which closely resembles the experimental one.

Williams and Daniels[3] made a series of careful measurements of the specific heat of ethyl benzene and carbon tetra-chloride, and noted some curious "humps" in the curves. They have suggested a mobile type of crystal lattice as a possible explanation. It is doubtful, however, whether they are dealing with the same phenomena as the present series of experiments, for the "humps" are very remote from the boiling point.

The small variations in the specific heat observed near the initial boiling point only affect the total heat to a very slight extent. Looking at the total heat table appended, it will be seen that at the initial boiling point of fraction No. 2 (100° C.) the total heat is 48·29 calories per gramme, whereas assuming the straight line formula for specific heat obtained between 0° C. and 60° C. to hold up to 100° C., a total heat of 48·19 calories per gramme is obtained, which is only a difference of about 1 part in 500. The results obtained by the continuous mixture method (Part III.) appeared to indicate that the specific heat-temperature relation is linear right up to the initial boiling point. But as the accuracy of these experiments is not much better than 1 part in 500, this only means that the variation of the specific heat curves from linearity cannot be greater than that measured for fractions Nos. 1 and 2. Thus although the unusual variation of the specific heat found by these experiments is of great physical interest, in practice it is relatively unimportant, since in any practical problem all that is required is a knowledge of the change of total heat with temperature. The following table has therefore been drawn up and gives the total

heat of the fractions from 0° C. up to their initial boiling points at intervals of 10° C. In each case the value was taken as zero at 0° C. The values for fractions Nos. 3, 4 and 5 were calculated from the equations :—

$$\text{Fraction No. 3.}—H=0{\cdot}4305t+0{\cdot}0005t^2.$$
$$\text{Fraction No. 4.}—H=0{\cdot}4282t+0{\cdot}0005t^2.$$
$$\text{Fraction No. 5.}—H=0{\cdot}4217t+0{\cdot}0005t^2.$$

For fraction No. 2 up to 60° C. the values were calculated from the equation :—

$$\text{Fraction No. 2.}—H=0{\cdot}4315t+0{\cdot}0005t^2,$$

but above this temperature values were obtained by graphically integrating the specific heat curve. This method was employed for fraction No. 1 over the whole range of temperature.

From this table the mean specific heat at any temperature can be readily calculated to an accuracy of not less than 0·2 per cent.

TABLE VIII.

TOTAL HEAT, CALS./GM.

Temperature.	Fraction.				
C°.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
0	0·00	0·00	0·00	0·00	0·00
10	4·41	4·37	4·36	4·33	4·27
20	8·91	8·83	8·81	8·76	8·63
30	13·49	13·40	13·37	13·30	13·10
40	18·19	18·06	18·02	17·93	17·67
50	23·00	22·83	22·78	22·66	22·34
60	27·95	27·70	27·63	27·49	27·10
70	32·97	32·68	32·59	32·42	31·97
80		37·77	37·64	37·46	36·94
90		42·98	42·80	42·59	42·00
100		48·29	48·05	47·82	47·17
110			53·41	53·15	52·44
120			58·86	58·58	57·80
130				64·12	63·27
140				69·75	68·84
150				75·48	74·51
160					80·27
170					86·14

2. *The Variation of Specific Heat and Total Heat with Specific Gravity.*—The relation between the specific heat at any one temperature and the specific gravity is not quite linear (Fig. 12) ; over the range of specific gravity covered, however (0·76—0·83), a linear relation is a very good approximation. Curves representing the equations given by Fortsch and Whitman,[4] and by Cragoe,[5] have been included in Fig. 12, and it will be observed that these give values about 5 per cent. too high.

The present results lend further support to the statement made in a previous paper,[1] that the temperature coefficient of specific

heat is not dependent upon the specific gravity, as the equations of Fortsch and Whitman and of Cragoe require. It is possible that such an idea may have resulted from the inclusion of that part of the specific heat curve near the boiling point, where it

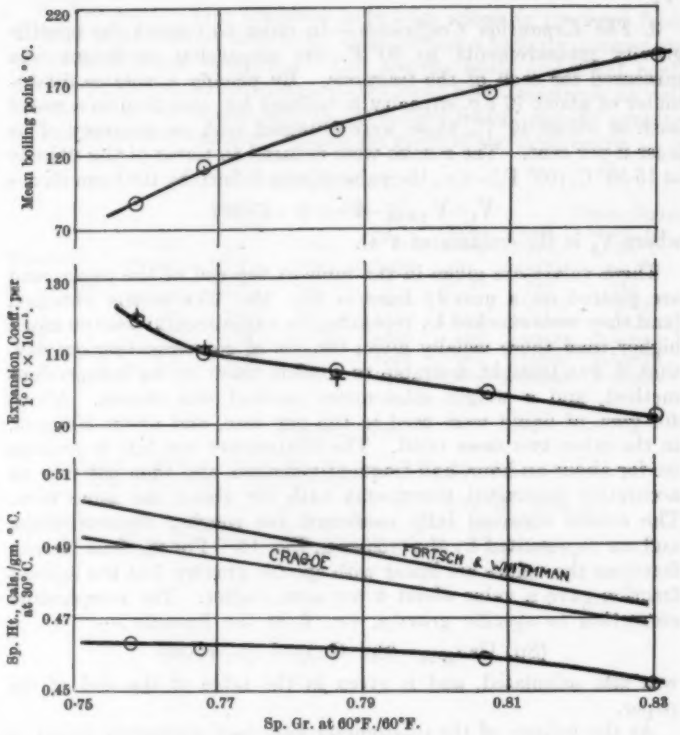

FIG. 12.

Specific Gravity relation of : (a) Specific Heat.
(b) Expansion Coefficient.
(c) Mean boiling point.

deviates from linearity. The results support Cragoe's conclusion, from his survey of the literature,[5] that "the results on oils from naphthene base crudes are systematically lower by about 2 per cent. than the values calculated from the equation."

As long as the rate of increase of specific heat per degree is constant, and the same for fractions of different specific gravities, the total heat-gravity relation will also be linear. Now as these conditions are almost exactly fulfilled in the present case, it is concluded that the total heat-gravity relation is, to a good approximation, linear.

3. *The Expansion Coefficients.*—In order to correct the specific gravity measurements to 60° F. the expansion coefficient was measured for each of the fractions. By placing a volume dilatometer of about 17 c.c. capacity in melting ice, and then in a water bath at about 40° C., these were obtained with an accuracy of at least 2 per cent. The results were reduced to terms of the volume at 15·56° C. (60° F.)—*i.e.*, the value of a as defined by the formula :—

$$V_t = V_{15\cdot56} - 1 + a\ (t - 15\cdot56)$$

where V_t is the volume at t° C.

These values are given in the table at the end of the paper, and are plotted on a gravity base in Fig. 18. The results obtained (and they were checked by repeating the experiments) were so much higher than those usually given for oils of corresponding gravity, that it was thought desirable to confirm them by an independent method, and a weight dilatometer method was chosen. About 400 gms. of liquid were used in the one case, and about 200 gms. in the other two cases tried. The dilatometer was left in melting ice for about an hour, and frequently shaken, and then put into an accurately controlled thermostat bath for about the same time. The results obtained fully confirmed the rougher measurements, and are represented by the crosses in Fig. 12. For the four heavier fractions the values are linear with specific gravity, but the lightest fraction gave a value about 4 per cent. higher. The temperature correction to specific gravity, *i.e.*, b in the formula :—

$$(\text{Sp. Gr.})_{15\cdot56} = (\text{Sp. Gr.})_t - b\ (t - 15\cdot56)$$

was also calculated, and is given in the table at the end of the paper.

As the volume of the dilatometer had been accurately found at various temperatures, it was possible to calculate the specific gravity from the series of accurate measurements. The values so obtained agreed with the hydrometer measurements to 2 or 3 in the fourth place of decimals.

The connection between the mean boiling point and the specific gravity, which is exhibited in Fig. 12, calls for no particular comment.

Since the mean molecular weight is a linear function of the specific gravity (Part IV.), it follows that statements regarding

the relations of other quantities to specific gravity apply equally well to molecular weights and vice versa.

Some further relationships have been given by Mr. Steed in Part IV., and are therefore not repeated here, but the figures are given in the summary below.

4. *Summary.*—Five fractions have been specially prepared from Miri oil, so as scarcely to overlap, thus forming a basis for comparison of some of their properties. The specific heat, and total heat, and their variation with temperature have been measured, as well as the mean molecular weight, refractive index, specific gravity and expansion co-efficient. These are given in the table below :—

TABLE IX.

Fraction No.	Boling range. ° C.	Sp. Gr. at 60°F./ 60°F.	Mean mol. wt.	Sp. Ht. at 30° C. Cals/gm °C.	Reft. Index at 20° C.	Coeff. Expn. per °C. (*a*)	Temp. Corrn. to Sp. Gr. at 60° F. per °C. (*b*).
1 ..	75–100	0·7583	88	0·4635	1·418	0·00118	0·00090
2 ..	100–125	0·7680	97	0·4615	1·423	0·00109	0·00084
3 ..	125–150	0·7862	108·5	0·4605	1·432	0·00104	0·00082
4 ..	150–175	0·8070	125	0·4582	1·443	0·00098	0·00079
5 ..	175–200	0·8295	140	0·4517	1·455	0·00092	0·00076

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The Estimation of Wax in Pitch.*

By W. Littlejohn and W. H. Thomas, A.R.S.M.

(Associate Members).

In research work concerning the preparation and use of petroleum residues suitable for road making and repairing purposes, a knowledge of the quantity and behaviour of the wax present has always been of paramount importance. Of no less importance is a convenient and reasonably quick method of estimating wax content for the routine testing of samples of petroleum pitch and heavy residues.

Most of the better-known methods are not suitable as routine tests, owing either to defects in the methods or to the excessive time taken for the estimation.

The Holde and the Cross methods are similar in that the asphalt is first distilled and the wax in the distillate is determined by cold precipitation from ether-alchol mixtures. Their disadvantages are that, firstly, the distillation is uncontrolled as regards speed and temperature rise; and secondly, insufficient emphasis is laid on the relative proportions of distillate to solvent during the precipitation.

Marcusson's method depends on the extraction of "vaseline" from the pitch by acid and soda treatment following the precipitation of "hard asphalt" by petroleum ether. The "vaseline" is retorted, and the wax in the distillate estimated by Holde's method. The method is complicated and occupies a great deal of time, but, in the consideration of various authors, is the most accurate of any.

The Schwarz method and the original (1924) method of the Institution of Petroleum Technologists are very similar and consist of coking the pitch with sulphuric acid. The former uses only one-tenth of the acid used in the latter, and extracts the coke with petroleum ether, evaporates the solvent, and estimates the wax by Holde's method. The Institution of Petroleum Technologists' method gives no control of the coking with sulphuric acid, and extracts the wax directly with ether-alcohol mixture. Of the two methods, that of Schwarz is preferable, but both apparently ignore the importance of the solubility of wax in the solvent.

* Paper received October 15th, 1930.

The Institution of Petroleum Technologists' new method (1929)[1] for the determination of wax in crude oil consists of a controlled cracking distillation followed by the estimation of wax in the distillate by a variation of Holde's method. The method is superior to other cracking distillation methods by virtue of the control of distillation conditions, but very little attempt is made to control the ratio of solvent to distillate. The method is not applicable to the estimation of wax in pitch owing to the maximum temperature of distillation being only just within the lower limits of the boiling range of the majority of most pitches.

A variety of solvents have been suggested for the solution and precipitation of wax from oil-wax mixtures, but whereas most are suitable for the purpose, the majority are difficult to recover in the pure state and hence prove very expensive in use. Some of the solvents suggested are as follows:—1, ether-alcohol mixture; 2, nitrobenzene; 3, acetone; 4, methylethyl ketone; 5, ethylene dichloride; 6, ethyl acetate; 7, butanone.

Of these, in the writers' opinion, acetone is the most suitable because of the relatively long range of temperatures over which it can be used, of its ease of recovery in the pure state with comparatively little loss, while, unlike alcohol-ether mixture, only one material is required.

It has been found that, using different methods, varying results can be obtained from the same sample of pitch. Not even does the ratio of percentages obtained from different pitches by one method agree with that obtained by another method. This may be explained by the varying chemical composition of the asphalts, which re-act unequally towards heat, sulphuric acid, etc. The cracking distillation methods invariably give considerably higher results than those depending on the sulphuric acid-coking methods. The reason for this is obscure, but experience points to the view that, in the latter method, the treatment with sulphuric acid tends to give an oil-wax mixture which is practically a "vaseline" in character. Vaseline, although conceivably consisting of oil and wax in some peculiar amorphous form, is far more insoluble in solvents such as acetone than is the oil and wax mixture obtained by cracking distillation. It is possible, therefore, that the acid-coked pitch cannot be freed easily of its content of oil and wax, and that this is responsible for the low results. Again it is very evident from the numerous determinations made of wax in pitch that unless a very carefully standardised method is used, any wax content which is quoted should be accompanied by a statement as to the method adopted, the solvent used, the ratio of

[1] "Standard Methods of Testing Petroleum and Its Products." Second edition, 1929. The Institution of Petroleum Technologists.

solvent to oil-wax mixture, the temperature of precipitation, and the melting point of the final wax obtained.

It will be realised that this method of correlating wax contents obtained by various methods would be extremely difficult if not impossible to carry out, and that the only solution to the problem is to devise a standard method of analysis in which all the variables which affect the apparent wax content are definitely and carefully controlled.

The experimental data detailed below indicate the variables and their effect on the ultimate estimated wax content.

A sample of soft pitch was used for the estimation of wax by (*a*) the sulphuric acid method, and (*b*) the cracking distillation method, the results obtained being as follows :—

TABLE I.

	Wax Content.
(A) Sulphuric acid method	0·03%
(B) Cracking distillation method	0·15%

It will be seen that method A gave results decidedly lower than method B. A known amount of paraffin wax was then added to the same sample of pitch and determinations on the mixture carried out by the two methods. The following results were obtained :—

TABLE II.

	Wax Content.
Calculated wax content	3·05%
(A) Sulphuric acid method	0·93%
(B) Cracking distillation method	2·38%
" " "	2·96%
" " "	3·06%

Again, method A gave lower results than method B, but the results from the latter were not altogether concordant. When, however, the cracking distillation method was applied to waxy pitches the discordancy was even greater, due to the fact that the wax present in the pitch varied from the lowest to the highest melting point, and the effect of the uncontrolled variables on these waxes was increased very considerably. The following results will illustrate this point :—

TABLE III.

	Wax Content.
Residue from mixed base crude oil (1)	11·8%
" " " " (2)	10·2%

It was finally decided, therefore, to adopt the cracking distillation method, because it appeared to give the highest and therefore, presumably, the most correct results. Again, the adoption of such a method would bring it in line with the current method of the

Institution of Petroleum Technologists for the estimation of wax in crude oil. In addition, it was decided to use acetone as the precipitating medium for the reasons already given.

In the preliminary work it was found that the following were the variables which had direct effects on the estimated wax content :—

1. Temperature of precipitation.
2. Extent of dilution of oil-wax mixture with acetone
3. Speed of distillation.

Temperature of Precipitation.—A moderately large quantity of a suitable heavy waxy crude residue was distilled to coke from a glass retort at a uniform speed. Aliquot portions of distillate were weighed out and diluted with acetone to the extent of 15 c.c. of acetone per gramme of distillate. The mixtures were cooled to various temperatures and the precipitated wax removed by filtration through a jacketed filter. The wax was washed with the minimum quantity of acetone (cooled to the required temperature) dissolved off the filter with hot petroleum ether, and the solution evaporated to constant weight. The results obtained are given below and shown graphically in Fig. 1 :—

TABLE IV.

Temperature of Precipitation.	Percentage of Wax.
32° F.	3·9%
20° F.	5·35%
10° F.	8·8%
0° F.	10·3%

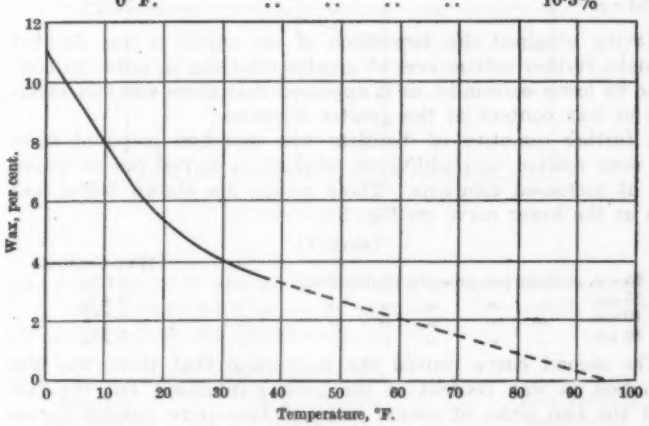

FIG. 1.

The cloud point of the solution of distillate in acetone was found to be 96° F., and therefore at this temperature the estimated wax

content would be nil. Thus, from a temperature of about 32° F. to 96° F. the wax content decreases slowly, whereas below 32° F. the percentage increases comparatively rapidly. This rapid increase indicates either the precipitation of the softer waxes in addition to the harder, or the precipitation of a mixture of oil, wax and resin at the lower temperatures. It would thus appear that the more correct results would be obtained by the determination of the wax content at a temperature in the neighbourhood of 32° F.

It is very evident, however, that an accurate definition of wax *per se* is virtually impossible, and that at the best wax can only be described by limits of melting points or by a description of its method of preparation, that is to say, the temperature of precipitation and the quantity and type of solvent used.

Extent of Dilution of Oil-wax Mixture with Acetone.—Using some of the same sample of distillate prepared for the previous series of experiments, solutions in acetone of various concentrations were prepared. Wax contents were determined by cooling to 0° F., filtering off the precipitated wax through a jacketed filter, washing with acetone and determining the weight of wax as before. The following results were obtained, and these are shown graphically in the upper curve on Fig. 2.

TABLE V.

	Wax Content.
10 c.c. acetone per gramme of distillate	14·6%
15 c.c. " " " " "	10·3%
30 c.c. " " " " "	6·2%

Having obtained the disposition of the curve, it was decided to make further estimations at greater dilutions in order to continue its lower extremity, as it appeared that there was less variation in wax content at the greater dilutions.

A further quantity of distillate was therefore prepared from the same residue, and additional estimations carried out as before but at increased dilutions. These results are shown below and also as the lower curve on Fig. 2:—

TABLE VI.

	Wax Content.
25 c.c. acetone per gramme of distillate	3·5%
35 c.c. " " " " "	3·4%
40 c.c. " " " " "	3·2%
50 c.c. " " " " "	3·1%

The second curve proved the contention that there was less variation in wax content at the greater dilutions, but the fact that the two series of results occupied two quite distinct curves showed that the conditions of the two distillations must have been different and to have had a definite effect on the type and quantity of wax distilled over,

Effect of Distillation Conditions.—Distillations were carried out on heavy residue in such a manner that the speed of distillation was different in each case. Wax contents of the distillates were

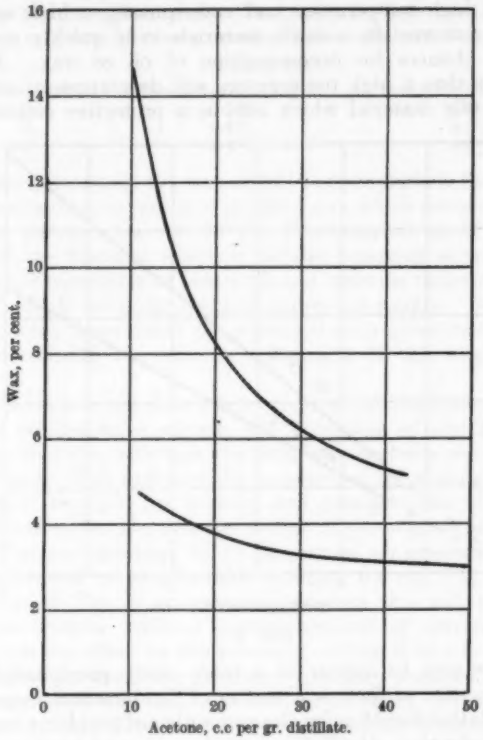

FIG. 2.

determined at 0° F. and at 32° F., using acetone to the extent of 35 c.c. and 70 c.c. per gramme of distillate. The results obtained are shown below and graphically on Fig. 3.

TABLE VII.

Speed of Distillation.	Wax Content determined at 0° F.	Wax Content determined at 32° F.
1 drop/sec. ..	3·4%	2·3%
2 drops/sec. ..	6·6%	4·6%
3 drops/sec. ..	9·8%	6·7%

The importance of distillation conditions will be seen readily, for, with a high speed of distillation, high results are obtained and, conversely, a low rate gives low results. No opportunity has yet occurred to determine the reason for this, but it is conceivable that a high temperature and consequently a high speed of distillation removes the volatile materials very quickly and thus lessens the chances for decomposition of oil or wax. Another possibility is that a high temperature will decompose or alter the resinous or oily material which acts as a protective colloid, thus

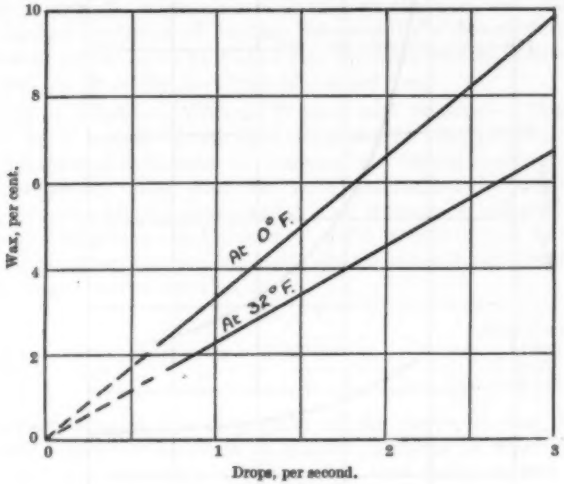

FIG. 3.

allowing the wax to appear in a more easily precipitated form. This, as a matter of fact, is a matter of fundamental importance, for its elucidation would make clear a number of problems connected with the production, distillation and dewaxing of lubricating oils.

It was found, subsequently, that it is easier to control the distillation by means of a predetermined temperature rise than by a speed of distillation.

Having investigated the effect of the variables on the estimation of wax in pitch, a tentative method was drafted out and tried. This method consisted essentially of distilling a weighed amount of the sample from a glass retort, using definite degrees of temperature rise. The distillate was weighed and dissolved in acetone to the extent of 35 c.c. per gramme of distillate. The solution was cooled to 0° F., and the precipitated wax removed and weighed.

The wax obtained was again dissolved in acetone, this time to a dilution of 70 c.c. per gramme of wax. The solution was cooled to 32° F., held at this temperature for 20 minutes and the precipitated wax removed, weighed and calculated on the original sample.

Some results obtained by this method when used to estimate the wax content of heavy residue are as follows :—

TABLE VIII.

Estimation.	Precipitation at 0° F.	Precipitation at 32° F.
1 ..	8·2% ..	4·9%
2 ..	6·8% ..	4·2%
3 ..	7·1% ..	4·6%

Reprecipitation of the wax at 32° F. is important, firstly, because it ensures a relative purity of the final wax which cannot be obtained by one precipitation at 32° F. Precipitation at 0° F. removes most of the material which is usually regarded as wax, together with small quantities of heavy oil and resinous material, the inclusion of which naturally leads to erroneous results. Secondly, the wax content determined by reprecipitation gives results more in accordance with the current conception of the wax content of pitches.

It has been found that when carrying out duplicate estimations of wax on the same sample, the quantities of distillate are not always the same, although the final wax contents were reasonably concordant. This indicates the necessity of calculating the amount of acetone required for solution and precipitation on the weight of distillate rather than on the weight of the original sample taken. In the first precipitation, 35 c.c. of acetone per gramme of distillate has been found to be a suitable quantity for use, for, from a consideration of Fig. 2, an amount less than this will tend to give erroneous results, while a greater amount of solvent will have very much less effect on the accuracy. Thus, if 35 c.c. per gramme of distillate be used, the minimum quantity required for washing the precipitated wax will have little or no effect, provided that the washings be kept at or below 5 c.c. per gramme of distillate. With regard to the reprecipitation, 70 c.c. of acetone per gramme of wax has been found to be the minimum quantity required to effect complete solution.

Although the tentative method gave fairly concordant results (±0·4%), it was found that by attention to certain details it was possible to increase the accuracy to ±0·2%. The modifications included :—

(*a*) The provision of means for maintaining an even rise in temperature.

(*b*) Adequate screening of the retort and bath to minimise the effect of draughts, cold air, etc.

(*c*) The washing of the retort neck with petroleum ether in order to dissolve the oil, resin and wax left there after distillation.

(*d*) The addition of the petroleum ether washings to the main bulk of distillate and subsequent evaporation of the solvent on the water bath. This evaporation also removes any light cracked products present, which may tend to interfere with the precipitation of the wax.

The following is the final draft of the method of estimating the wax content of pitches :—

Ten grammes of the sample (±0·5 grammes) are weighed into a 70-c.c. glass retort. The temperature as indicated by the retort thermometer is raised to 450° C. or to the initial boiling point of the sample, which ever occurs first, at a uniform rate of from 40–50° C. per minute. From 450° C., or the initial boiling point of the sample, the temperature is raised 15° C. per minute until a temperature of 500° C. is attained. This temperature (500° C.) is maintained for five minutes, after which the retort is allowed to cool and its neck washed free from oil, resin and wax with hot petroleum ether. The washings are collected together with the distillate in a previously weighed conical flask of 150 c.c. capacity, and the whole evaporated on the water bath, placed in the steam oven for 30 minutes, cooled and weighed. Pure water-free acetone is next added to the weighed distillate in the proportion of 35 c.c. of acetone per gramme of distillate, and the mixture refluxed for five minutes or until complete solution is obtained. The solution is now cooled under the tap to 60–70° F., immersed in ice and salt mixture, cooled to 0° F., and held at this temperature for five minutes. The cold mixture is next filtered through an ice and salt jacketed funnel containing a 9 cm. filter paper (Whatman 44). Filtration should be as fast as possible, aided by only moderate suction, and *great care should be taken that the wax is not allowed to "pull-down" into a hard cake, but remains as a soft semi-liquid mass until washing is complete.* The washing should be carried out with the minimum quantity of cold acetone at 0° F., the quantity not exceeding 5 c.c. of acetone per gramme of distillate, finally draining the filter under suction. The filter paper with its contained wax is transferred to a second funnel and the wax dissolved with hot petroleum ether into the original weighed flask. The solution is now evaporated on the steam bath, placed in the steam oven for 30 minutes and the wax cooled and weighed. The percentage of wax precipitated at 0° F. on the original sample should be calculated at this stage.

The wax is taken up again in acetone, but in the proportion of 70 c.c. of acetone per gramme of wax and refluxed for five minutes, or until complete solution is effected. The solution is cooled rapidly to 32° F., and maintained at this temperature for 20 minutes, after which it is filtered rapidly, using the same precautions as before, through an ice and water jacketed funnel containing a 9 cm. filter paper (Whatman 44). Washing is carried out with the minimum quantity of cold acetone at 32° F., the quantity not exceeding 5 c.c. of acetone per gramme of wax, finally draining the filter under suction.

The filter paper is transferred to a second funnel and the precipitated wax dissolved with hot petroleum ether into the original weighed receiver. The solution is evaporated on the steam bath, placed in the oven for one hour, and the wax cooled and weighed. The wax is then calculated on the original sample, and the result expressed as "percentage of wax determined at 32° F. (and/or 0° F.) precipitated from acetone." The melting point of the wax

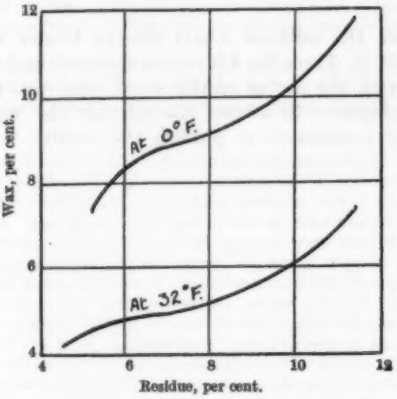

FIG. 4.

should be obtained and included in the result. Where possible, the test should be carried out in duplicate, the maximum discrepancy allowable being 0·4 per cent.

Although repeatable results could be obtained with an accuracy of ±0·2 per cent., it was thought that the best test would be to carry out estimations of wax in a series of pitches obtained by pipe still distillation of a moderately heavy waxy residue.

The results obtained on this series are as follows :—

TABLE IX.

Percentage Residue.	Wax Content at 0° F.	Wax Content at 32° F.	Melting Point of wax determined at 32° F.
11·4%	11·8%	7·4%	51·5° C.
9·0%	9·7%	5·5%	50·0°
7·3%	8·9%	5·1%	49·5°
6·4%	8·6%	4·8%	48·0°
5·2%	7·3%	4·6%	49·0°

Fig 4 shows the above results more conveniently in a graphical form.

The method given above has been described in greater detail than is usual with standard methods of testing, for in the authors' experience it is only by very careful attention to detail that reasonably concordant estimations of wax may be made. Indeed, although it has already been shown that, at the best, wax can only be estimated (and not determined), any method of wax estimation should be regarded more as a somewhat difficult analysis requiring careful and experienced manipulation than as a "standard method."

In conclusion, the authors would like to tender their grateful thanks to Dr. F. B. Thole for his encouragement and many helpful suggestions during the course of this work, and also to the Anglo-Persian Oil Company, in whose laboratories the work has been carried out, for permission to publish the results.

CURRENT PETROLEUM NOTES.

Natural-Gasoline Plants in the U.S.A.—On January 1st., 1930, there were 1,035 natural-gasoline plants in the U.S.A., with a total daily capacity of 10,516,000 gallons. Of these plants 999 were in operation with a daily capacity of 10,278,000 gallons. This compares with 1,155 plants, of 8,048,000 gallons daily capacity on January 1st, 1928, when 1,600 were in operation. During 1929 the average total daily capacity of the operating plants was 9,899,000 gallons, with an average daily production of 6,015,000 gallons.

The absorption method of extraction rose from 5,476,000 gallons daily capacity on January 1st, 1928, to 7,956,000 gallons on January 1st, 1930, when it comprised 76 per cent. of the total. During the same period the charcoal method decreased from 214,000 to 186,000 gallons daily capacity.—U.S. Bureau of Mines Information Circular 6279.

Formaldehyde from Waste Natural Gas.—Investigations made by the U.S. Bureau of Mines showed that traces of formaldehyde were formed when methane-air mixtures were suitably heated, and later work showed that gaseous catalysts, such as oxides of nitrogen, increased the yield considerably. The investigations have shown, however, that until further developments are made the excessive cost of nitrogen oxides renders this method impracticable.

Ethyl Mercaptans for Detection of Gas Leaks.—The U.S. Bureau of Mines has investigated the use of highly odorous substances as agents for detecting leaks in fuel gas systems and found the mercaptans to be practicable and cheap.

For house mains, 7·7 to 9·3 lb. per million cu. ft. of gas were effective, and for underground mains and service lines, 31·0 to 46·5 lb. per million cu. ft. Further details are given in U.S. Bureau of Mines Report of Investigations 3007.

Recovery of Oil from Sands by Gas Drive.—Experimental data show that a number of factors affect the efficient recovery of oil from sands by the "Gas drive." (1) The density of a pressure medium has some effect upon oil recovery with a "gas drive," because of the greater kinetic energy available in a denser medium. (2) Control of the injection rate is advantageous because by such control gas-oil ratios and energy expended may be reduced. (3) The solubility of a pressure medium is important, not only because of a reduction of the viscosity and the surface tension of the oil, but also because of an increase in the volume of the oil due to the dissolved gas, which increases the saturation of the sand and therefore tends to reduce gas slippage. If the increase in the volume of the oil is not sufficient to fill the voids completely, a further benefit may be derived by expansion of the gas from solution. Knowing the frothy consistency of oil with gas in the occluded state, a similar condition may be visualised within the body of sand when gas expands from solution. As this condition can probably be brought about within the pore spaces of the sand, its effect would be to more completely fill the interstices with an oil-gas mixture. This occupancy of the pore spaces would tend to prevent slippage of gas through the less-saturated portions of the sand, and complete filling of voids in this manner would reduce "by-passing." Under such conditions, more of the piston effect would be introduced into the "Gas drive" by giving the pressure medium a surface to work against. This explanation probably applies to instances in field operations where "by-passing" has been reduced by the use of "wet" gas.—U.S. Bureau of Mines Report of Investigations 3035.

Standardization of Chemical Apparatus.—The report of the Deutsche Gesellschaft für Chemisches Apparatewesen indicates remarkable progress in the standardization of chemical apparatus, and about 80 pamphlets have been issued by the various sub-committees. The standardization of hydrometers and pyknometers is now being undertaken in collaboration with other bodies. A series of pamphlets on the standardisation of rubber tubing, on the classification of laboratory glassware according to its hydrolytic behaviour, and on rapid methods for the investigation of glass apparatus and filter paper is nearing completion.

REVIEWS.

SCHMIERMITTEL. C. Walther. Verlag von Theodor Steinkopff, Dresden and Leipzig, 1930. Pp. $\times + 144$.

The author presents a very complete and convenient survey of the theoretical and practical contributions made to the subjects of lubricating oils and lubrication during recent years. The material, collected from a widely scattered literature, deals particularly with lubricating oils of mineral origin. It consists mainly of a series of concise abstracts arranged in logical sequence and in narrative form with copious footnote references to the original sources of information.

The first chapter deals with the lubricating value of lubricants and includes sections on the thickness and properties of lubricating films, oiliness, the results of Hardy on the effect of increasing molecular weight on the lubricating power of homologous series of pure substances, capillary properties, the work of Dallwitz-Wegner, Wilson and Barnard, and Bachmann and Brieger on the heat of wetting, also brief references to various oil testing machines.

The preparation of lubricating oils from petroleum is dealt with in the next section, the first part of which is devoted to recent developments in distillation technique which has followed three main directions, namely, the replacement of large shell stills by tube stills, the employment of the lowest possible distillation pressure and reliance on fractional condensation rather than fractional distillation. As examples of pipe still and fractional condensation practice diagramatic flow charts of the plants of Harnsberger, Borrmann and Vorbach are given, as well as brief descriptions of the methods of Steinschneider, Schultz and others. No indication is given of the economic or industrial value of the various processes. Under dewaxing methods mention is made of the Sharples centrifugal process, the Weir "filter-aid" dilution filtration process and references are given to the work on the use of solvents or diluents not of petroleum origin, such as acetone or alcohols. Various refining methods, such as the addition of alkalies to the oil before distillation, the employment of special methods in sulphuric acid treating and the use of organic liquids in subsequent washing operations and the application of the Edeleanu process, are referred to. Bleaching earths and silica-gel are also dealt with. The synthetic production of lubricating oils by polymerisation or hydrogenation from petroleum, coal and various coal-tar oils and the conversion of non-viscous to viscous oils by the electrical discharge or voltol process are discussed.

The third chapter deals with the chemical composition of lubricating oils, the changes which turbine, transformer and internal combustion engine oils undergo in use and by oxidation, the crystallisation properties of paraffin

and the chemical decomposition of lubricating oils and their reactions with various reagents, such as bromine and sulphuric acid, and suggested methods for determining unsaturated and aromatic constituents.

The fourth and last chapter deals with the analysis of lubricating oils. Viscometry is treated at some length and most of the instruments in use throughout the world for viscosity determination are mentioned. Formulæ for the temperature and pressure coefficients of viscosity and for calculating the viscosity of blends are given. Reference is made to recent publications on the determination and significance of the various characteristics of oils. A tabular comparison of some twenty oxidation tests for transformer, turbine and automobile oils and sections on spontaneous ignition points, optical measurements and cold test determinations are included. Separate patent, name and subject indexes are appended. The book may be regarded as a most useful supplement to such works as those of Gurwitsch and Holde in its particular province.

R. W. L. Clarke.

Petroleum Engineers Handbook. "Petroleum World," Los Angeles, 1930. Pp. 496. $5.

The first edition of the "Petroleum Engineers Handbook" was issued on July 15, 1930, by the "Petroleum World" of Los Angeles, California.

It deals very comprehensively with the current methods, improved tools and applications now in use in the Californian Oilfields, and clearly shows the increasingly important part now being played by technical men in everything that appertains to oil production.

While one is impressed by the great variety of problems a petroleum engineer may be called upon to solve during his ordinary day's work, each section is written by an authority who has proved his ability in dealing with these practical problems and has therefore just claims to be called a "Specialist." The result is a handbook which indicates the methods adopted for dealing with each problem and furnishes one with a mine of data and curves in a very usable form.

Whatever branch of oil production engineering one may be employed in, it would be difficult for one to read through the book without finding it of practical use, and, better still, without learning where useful information to facilitate the solution of future problems may readily be found, when necessary.

The handbook is very fully illustrated with photographs and curves, which make it interesting reading and add to the ease with which the particular data required for the problem being handled can be extracted.

It is hoped that this may be the first of a long series of editions of this handbook, and that future editions will be as thoroughly up to date in their description of the constantly improved methods the petroleum engineer is perfecting almost daily.

It is also hoped that the experience of other Oilfields, where different problems are met with, may be included in later editions, provided this can be done without unduly increasing the size of the book and making it unwieldy.

A. C. Hartley.

BOOKS RECEIVED.

THE MEASUREMENT OF A RAPIDLY FLUCTUATING FLOW OF GAS. J. G. King and B. H. Williams. Fuel Research Technical Paper No. 27. Pp. vi.+18. London: H. M. Stationery Office. 6d. net.

The method adopted at the Fuel Research Station for the measurement of the production of water-gas, where the flow is intermittent, consisted in measuring the pressure drops across an orifice inserted in a straight length of pipe, a continuous record being obtained by a photographic method. The results were satisfactory and the method, or a similar one using a Venturi tube, may be of use for a variety of purposes.

THE DETERMINATION OF AROMATIC, UNSATURATED AND NAPHTHENE HYDROCARBONS IN LIGHT OILS AND MOTOR SPIRITS. A. B. Manning and F. M. E. Shepherd. Fuel Research Technical Paper No. 28. Pp. iv+14. London: H. M. Stationery Office. 4d. net.

The analysis of light oils and motor spirits is dealt with and convenient methods described for determining the aromatic and unsaturated hydrocarbons.

PETROLEUM IN RUMANIA. M. Pizanty. Bucharest, "Moniteur du Pétrole Roumain," 1930. Pp. 100.

The author, as Chief Editor of the "Moniteur du Pétrole Roumain," is undoubtedly the best authority on the matter at present. The 1930 edition of this work, in English, presents the situation of the Rumanian petroleum industry with clearness from every angle of view. If the Rumanian, French and German editions of this book have brought the author thanks and congratulations, the English edition will undoubtedly be welcomed as filling a long-felt want. Foreign technologists have been lacking until now a trustworthy guide by means of which any one may form a just idea on conditions prevailing in the petroleum situation in Rumania.

The Rumanian oil industry is passing at present through a crisis which seems to have reached the top of the curve, judging by the vigorous means of relief taken recently. It intends to emerge from the present passivity to a completely active rôle, based on the quality of raw materials, geographic situation, and latent possibilities insufficiently exploited up to now, and will shortly draw the attention of all foreign circles. The work of Mr. Mihail Pizanty constitutes a valuable guide, without which it would be very difficult to penetrate from afar the complexity of the Rumanian oil industry in its present situation. The author has paid attention to Anglo-American circles through the publication of his interesting study in English.

BIBLIOGRAPHY OF ORGANIC SULPHUR COMPOUNDS. P. Bergstrom, R. W. Bost and D. F. Brown. Pp. 187. New York: American Petroleum Institute, 1930. $4.

The scope of this literature study has been limited to sulphur compounds which may occur in petroleum and to their properties, uses and removal from products. Over 2,500 references, with brief abstracts, are given and are divided into 34 groups. The second section deals with U.S. Patents and includes over 1,000 references. Only a limited number of copies of this valuable work are available.

CHRISTIAN LEU.